INSTRUMENTATION OF A SAVONIUS WIND
TURBINE

by

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TABLE OF CONTENTS

Chapter		Page
LIST OF FIGURES		iii
LIST OF TABLES		v
1.	INTRODUCTION	1
2.	SYSTEM HARDWARE	5
	2.1 Introduction	5
	2.2 Microcomputer	7
	2.3 4k RAM Expansion	10
	2.4 Multiplexer-Counter	11
	2.5 Angular Velocity Transducer	11
	2.6 Digital Anemometer	15
	2.7 Analog Anemometer	21
	2.8 Pressure Transducer	23
	2.9 Temperature Transducer	25
	2.10 Wind Direction Transducer	25
	2.11 Torque Transducer	29
	2.12 Electrical Power Transducer	31
	2.13 Alternator Voltage Transducer	31
	2.14 Analog to Digital Converter	34
	2.15 Lightning Protection	39
	2.16 Calibrations and Errors	42
3.	SYSTEM SOFTWARE	44
	3.1 Introduction	44
	3.2 MOS Technology Cross-Assembler	44
	3.3 Binned Data Acquisition	45
	3.4 Sequential Data Acquisition	47
4.	SYSTEM OPERATION	49
	4.1 Introduction	49
	4.2 Memory Allocation	50
	4.3 Paper Tape Format	50
	4.4 Data Reconstruction	50
5.	CONCLUSIONS	61
6.	ACKNOWLEDGEMENTS	62
7.	REFERENCES	63

TABLE OF CONTENTS (cont.)

Chapter Page

8. APPENDICES 65

APPENDIX A: Modification of the S.D.S. 4k RAM Board 66

APPENDIX B: Multiplexer-Counter Board 73

APPENDIX C: MP21 Connections 80

APPENDIX D: Cross-Assembler Reader 84

APPENDIX E: System Program Flow Charts 89

APPENDIX F: KIM-1 Data Collection Program Listing 105

APPENDIX G: System Operation 124

LIST OF FIGURES

Page

1.1-1. Wind Speed Historgram 3

1.1-2. The Kansas State University Savonius Wind Turbine 4

2.1-1. Block Diagram of the KSU Wind Laboratory Data Acquisition System 6

2.3-1. KIM-1 Memory Map 12

2.4-1. Block Diagram of the Multiplexer-Counter Board and Interfacing 13

2.5-1. Angular Velocity Transducer and Interface 16

2.6-1. Digital Anemometer Photo Chopper and Voltage Comparator 19

2.6-2. Diagram of the KSU Prototype Digital Anemometer Signal Conditioning, Gating and Pulse Rate Counter 20

2.8-1. National LX1602A Pressure Transducer and Interface Block Diagram 24

2.9-1. Westinghouse Temperature Transducer, Filter and Amplifier Block Diagram 26

2.10-1. +3 Vdc Regulator for Wind Direction Indicator 27

2.10-2. Wind Direction Indicator Connections 27

2.10-3. +5 Vdc Regulator for Air Pressure-Wind Direction Card . . . 28

2.10-4. Wind Direction Indicator Rose 28

2.11-1. Block Diagram of the KSU Savonius Wind Turbine Power Shaft 30

2.12-1. Electrical Power Transducer Block Diagram 32

2.13-1. Halfwave Rectifier for Alternator Output Voltage Transducer 33

2.14-1. MP21 Block Diagram 35

2.14-2. Input Protection for A/D (MP21) 38

LIST OF FIGURES (cont.)

		Page
2.15-1.	Lightning Protection Circuit	41
3.3-1.	Generalized Operating Scheme for Data Collection	46
3.4-1.	Flow Chart for Sequential Data Collection	48
4.3-1.	Paper Tape Format	52
4.3-2.	Example of Time Paper Tape File	53
4.4-1.	Analog Transducer Output Mapped into Bins	56
4.4-2.	Angular Velocity at Transducer Versus Bin Number	58
4.4-3.	Mechanical Power Versus Bin Number	59

LIST OF TABLES

		Page
2.2-1.	TTY-KIM-1 Connections	8
2.4-1.	KIM-1 Port B Bit Patterns for Peripheral Control	14
2.14-1.	MP21 Memory Map	37
4.2-1.	System Memory Allocation	51
4.3-1.	Output Record Tape	54

1. INTRODUCTION

Instrumentation of the Kansas State University (KSU) Savonius wind turbine was needed to develop a method of measuring turbine performance in free air. In the past, tests were performed on scale models in wind tunnels. These tests and results are difficult, if not impossible, to extrapolate in order to predict full scale performance. At the KSU Wind Laboratory we wanted to measure wind speeds and power output from the turbine in the proper way to determine wind turbine characteristics without the need of a full scale wind tunnel.

The power output of a turbine and the wind speed measured at the same time do not exhibit a one-to-one correlation. It is necessary to take large quantities of data to determine wind turbine performance by statistical methods.

The simple scheme of collecting wind data sequentially does not give good results. Poor results arise from the fact that there is a large amount of scatter or variation in the data. This scatter is attributed to the phenomenon that the effective instantaneous wind speed over the surface of the turbine is not equal to the instantaneous wind speed at the anemometer. In most cases, data taken sequentially are of little use due to this scattering. The method developed here for taking reasonable data is called the Method of Bins.

The Method of Bins assumes that statistically the wind speeds over the surface of the turbine and at an anemometer placed at the median height of that turbine are the same. In other words, if the wind speeds are sampled for a long enough period of time the mean and the variance of the

wind speed will be the same for both locations. With the Method of Bins, data are typically collected several times a second and the bin corresponding to each sampled value is incremented by one. When a bin becomes full, all bin contents are dumped to bulk storage.

The type of data taken by the Bin Method is illustrated in Figure 1.1-1. This is a histogram of actual wind speeds at about 10 m above the ground during a 4 minute period on March 31, 1978 at Manhattan, Kansas. Each bin represents a range of wind speed of 0.13 m/s. Bin 70 includes wind speeds between 10.13 and 10.26 m/s, for example. The wind speed was in this range 8 times during this particular test. The average wind speed for this period was 12.17 m/s (27.22 mph), somewhat above average but not uncommon for Kansas. The minimum wind speed measured was 10 m/s while the maximum was 15.37 m/s.

The KSU Savonius wind turbine shown in Figure 1.1-2 was completed in May 1977. This turbine was designed to deliver 5 kilowatts of three-phase electrical power to a load in an 11 meter per second wind speed. The turbine was built to study open air testing of wind machines. The major project goal was to develop a system by which any wind machine could be tested and analyzed. The Savonius tests, however, have turned out to be quite encouraging. Initial field testing in March 1978 indicated a peak coefficient of performance about equal to those of the Darrieus or large two-bladed propeller type wind turbines.

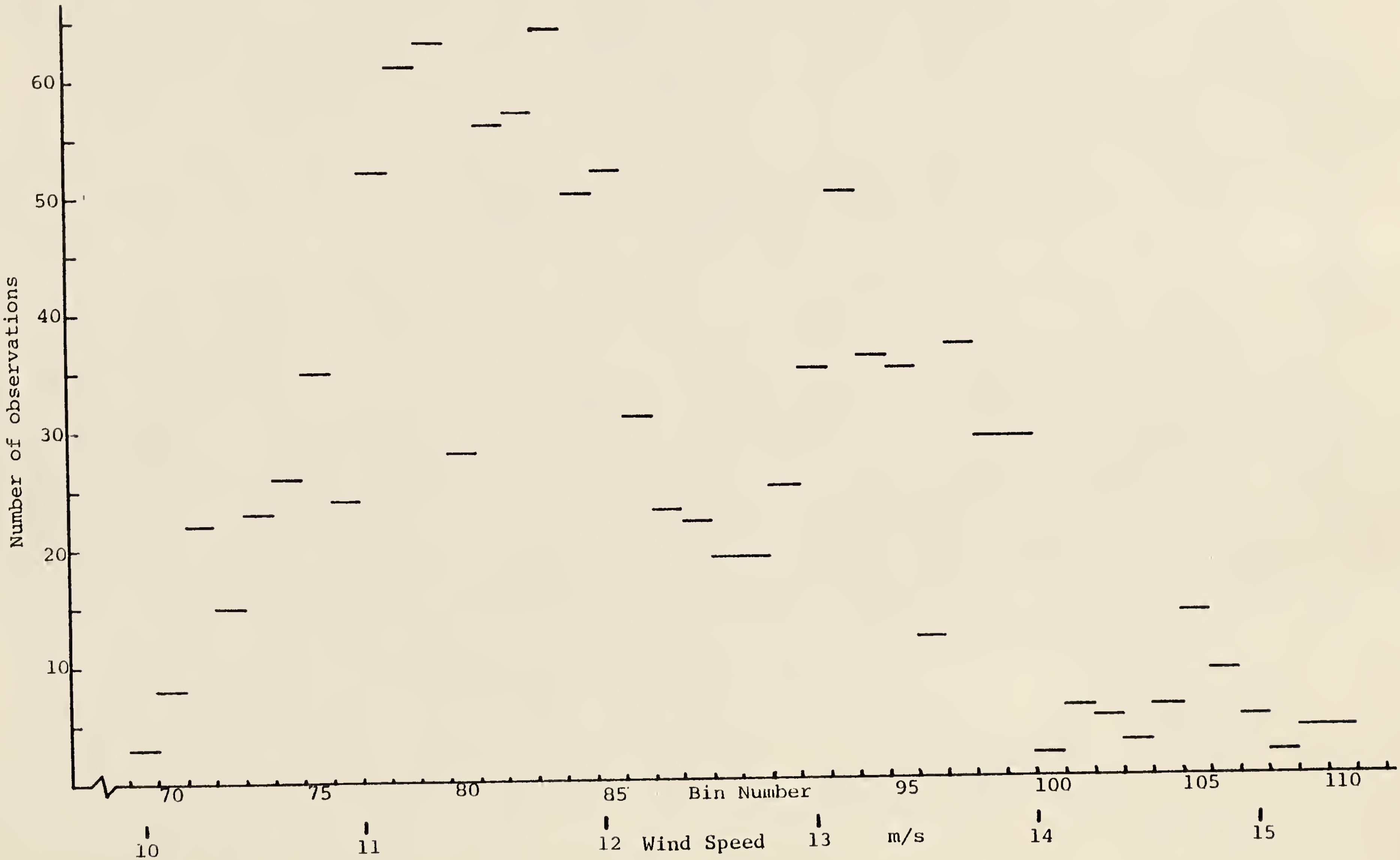


Fig. 1.1-1. Wind Speed Histogram.

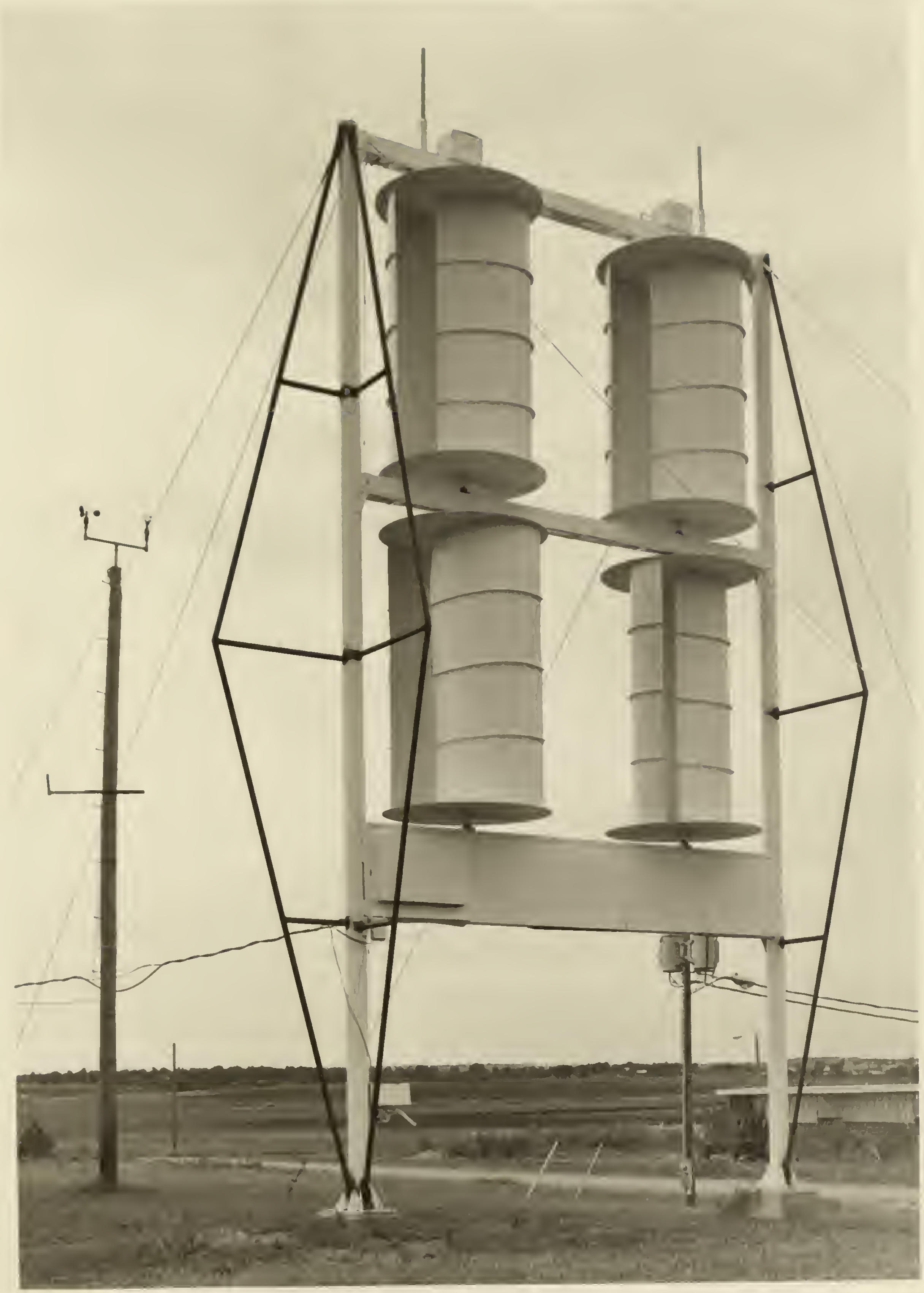


Fig. 1.1-2. The Kansas State University Savonius Wind Turbine.

2. SYSTEM HARDWARE

2.1 Introduction

The instrumentation necessary for the data acquisition from the Savonius wind turbine was a natural place for a microcomputer and a high quality analog to digital (A/D) converter. A block diagram of the data collection system is shown in Figure 2.1-1. The KSU Wind Laboratory instrumentation consists of a microcomputer, a paper tape punch, a variety of analog transducers, an angular velocity digital transducer and a digital anemometer. The microcomputer is a MOS Technology KIM-1 with an extra 4k of Random Access Memory (RAM) and a Burr-Brown analog to digital microperipheral. The A/D microperipheral has eight selectable differential inputs which are all connected to the transducers through RC filters for the reduction of high frequency noise. The microcomputer system utilizing a multiplexer board has an 8-bit digital Input-Output (I/O) port and two pulse rate inputs. These pulse rate inputs are connected to the digital anemometer and angular velocity transducer. Included on the multiplexer board is a paper tape punch digital interface for data output.

The instrumentation is powered by +8 Vdc regulated to +5 Vdc for the microcomputer, the digital portion of the A/D, the multiplexer-counter board, and the 4k RAM card. ±15 Vdc is needed for the A/D and +12 Vdc for the audio cassette interface. However, the cassette interface only needs +12 Vdc in the read mode and can remain disconnected at all other times.

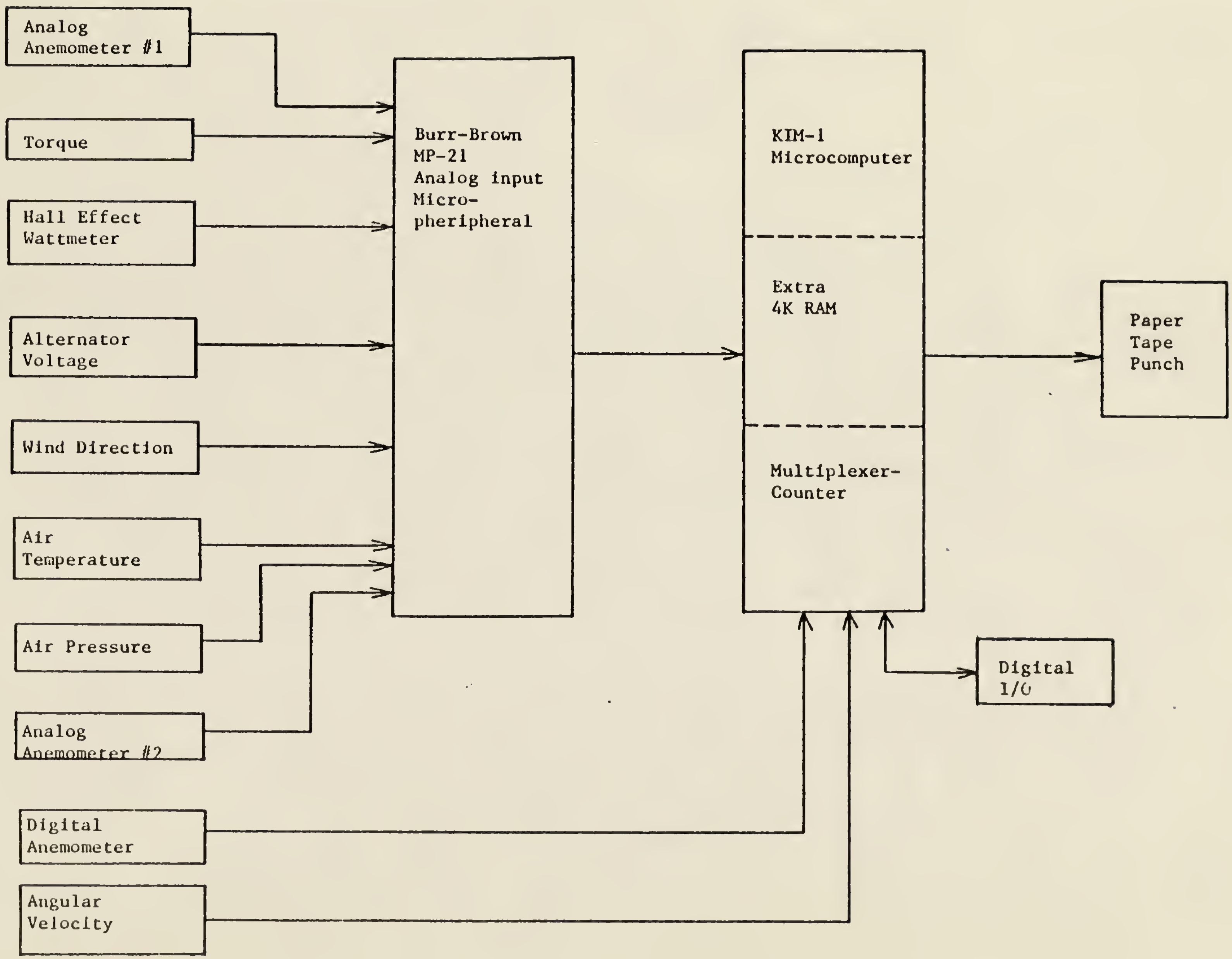


Fig. 2.1-1. Block Diagram of the KSU Wind Laboratory Data Acquisition System.

2.2 Microcomputer

The MOS Technology KIM-1 is a single board machine with a monitor residing in Read Only Memory (ROM) and with 1K bytes of RAM available for the user. The microcomputer employs a MCS6502 (6502) microprocessor as the Central Processing Unit (CPU). The 6502 is an 8-bit machine (8-bit bi-directional data bus) with a 16-bit program counter (16-bit address bus). Details of the 6502 can be found in the MOS Technology 6502 Hardware manual [1]. Internal registers in the CPU include one 8-bit accumulator, two 8-bit index registers--X and Y, an 8-bit stack pointer confined to page one, an 8-bit processor status register and a 16-bit program counter. Programming the 6502 is much the same as any present day 8-bit microprocessor with the exception of the zero page and zero page indexed address capabilities. This addressing ability allows for extended table programming operations to be done with ease. Details of the addressing can be found in the MOS Technology 6502 Hardware and Programming Manual [2].

One feature of the KIM-1 is its on board interfaces for TTY and audio cassette. The I/O ports, interrupt timer and hexadecimal display are also useful features. The TTY interface is a 4 wire 20 ma current loop configuration allowing a serial teleprinter to be connected directly to the KIM-1. The signal connections between the KIM-1 and TTY are given in Table 2.2-1.

The primary function of the TTY is to load cross-assembled programs from paper tape into the data acquisition system. By using the cross-assembly method for programming and receiving a paper tape, a hard copy of the system program can be on file at all times. The teleprinter may also be used for hard copy of data recorded by the system. This feature,

TABLE 2.2-1

TTY - KIM-1 Connections

KIM-1 Application Connector	KSU Standard Cinch Jones 8-pin Connector	
R	3	Keyboard Return
S	1	Printer Return
T	4	Keyboard
U	2	Printer

though not exploited by current software, could easily be added using routines in the KIM-1 monitor.

The audio cassette interface on the KIM-1 employs a frequency shifted signal to encode program information on cassettes. Audio quality cassettes can be recorded or read by routines in the KIM-1 monitor. Details of the audio interface are given in the KIM-1 user manual [3]. The audio cassette feature is used to load the system program into RAM. The system is powered on and reset from the keyboard. After reset the data collection program is loaded from audio cassette. This method allows user adjustable software to reside in RAM while keeping a semipermanent record of the program on tape. User adjusted software can be rerecorded on tape to save any user changes or adjustments. It can be useful to keep an extra copy of the program on tape in case of programming problems. This extra tape is not essential because of the availability of the hard copy paper tape received from the cross-assembler.

The I/O ports on the KIM-1 allow 15-bits of input and/or output partitioned as 8-bits from port A and 7-bits from port B. On the wind laboratory system, port A is multiplexed (1 to 4) to give 4 inputs and/or outputs. Two of these multiplexed ports are connected to pulse rate counters, one to the paper tape punch and one left for digital expansion. Port B is used to control the port A multiplexer, the paper tape punch, and receive interrupts from the timer on bit 7.

The interrupt timer is located on board in the MCS6530-002. This timer generates an interrupt upon count-out. It can be set at count-out or any other time by a write to the proper address. Details of the timer

address are given in the KIM-1 User manual Appendix H and in the MOS Technology MCS6502 Hardware Manual. Bit 7 of port B is switched to interrupt request (IRQ) on the KIM-1 Expansion Connector to allow use of both the timer and interrupts in software debugging.

The KIM-1 has a built-in display which allows information to be entered or passed to the user. This display has 6 digits of display and is normally operated as 4 digits of hexadecimal address and 2 digits of hexadecimal data. This display along with the KIM-1 hexadecimal keyboard is used to make user modifications to the program. During operation the display is used to exhibit currently sampled data. It may also display any channel or data value recorded by the microcomputer. The ability to display this information gives the user some type of feedback and reassurance that they system is operating properly.

2.3 4k RAM Expansion

The Wind Laboratory microcomputer memory was expanded by 4k bytes with the use of an S.D. Sales 4k Low Power Ram Board [4]. This board is plug compatible with the S-100 bus and includes 4096 8-bit memory words with buffered outputs and on board power regulation. 21L02 memory chips are used, each having a capacity of one bit at each of 1024 addresses.

The 4k board decoding must be modified for use with the KIM-1. Modification is accomplished by following the step by step procedure given in Appendix A after normal assembly of the board. Also provided in Appendix A is a memory march test for testing the RAM.

The intention of the modification is to provide memory in the K1, K2, K3 and K4 positions of the already decoded locations of the KIM-1.

See Figure 2.3-1. Modification is accomplished by disabling the S-D decoding and providing the proper decoding for the KIM-1. The modification can best be understood by referring to the logic diagram in Appendix A. IC 39 (7400) on the S-D board is altered from an active high NAND gate to an active low OR gate which is true when K1, K2, K3 and K4 are low. See KIM-1 User Manual.

2.4 Multiplexer-Counter

The KIM-1 microcomputer is interfaced to the digital anemometer, angular velocity transducer and the paper tape punch by the multiplexer-counter board. The board employs 4 CMOS 4052's for multiplexing port A of the KIM-1 to the 4 digital I/O ports. The 4052's are analog multiplexers and therefore care must be taken to set port A to an input before selecting input signals with the multiplexer, so that two outputs are not tied together. The multiplexer is controlled by bits CØ and C1. These control bits correspond to port B bit 4 and 5 respectively. Anyone of the four ports or devices can be selected by the appropriate bit pattern at port B. See Table 2.4-1. A block diagram of the multiplexer-counter board is shown in Figure 2.4-1. The paper tape punch is wired with a solid state relay for power control. The punch powers-on when selected, that is, when CØ and C1 are both zero. Details of the multiplexer, punch connections, multiplexer-counter card connections, angular velocity counter and digital anemometer counter are given in Appendix B.

2.5 Angular Velocity Transducers

The angular velocity of the wind turbine is measured by a magnetic pick-up from a 60 tooth gear enclosed in the Lebow torque transducer. See

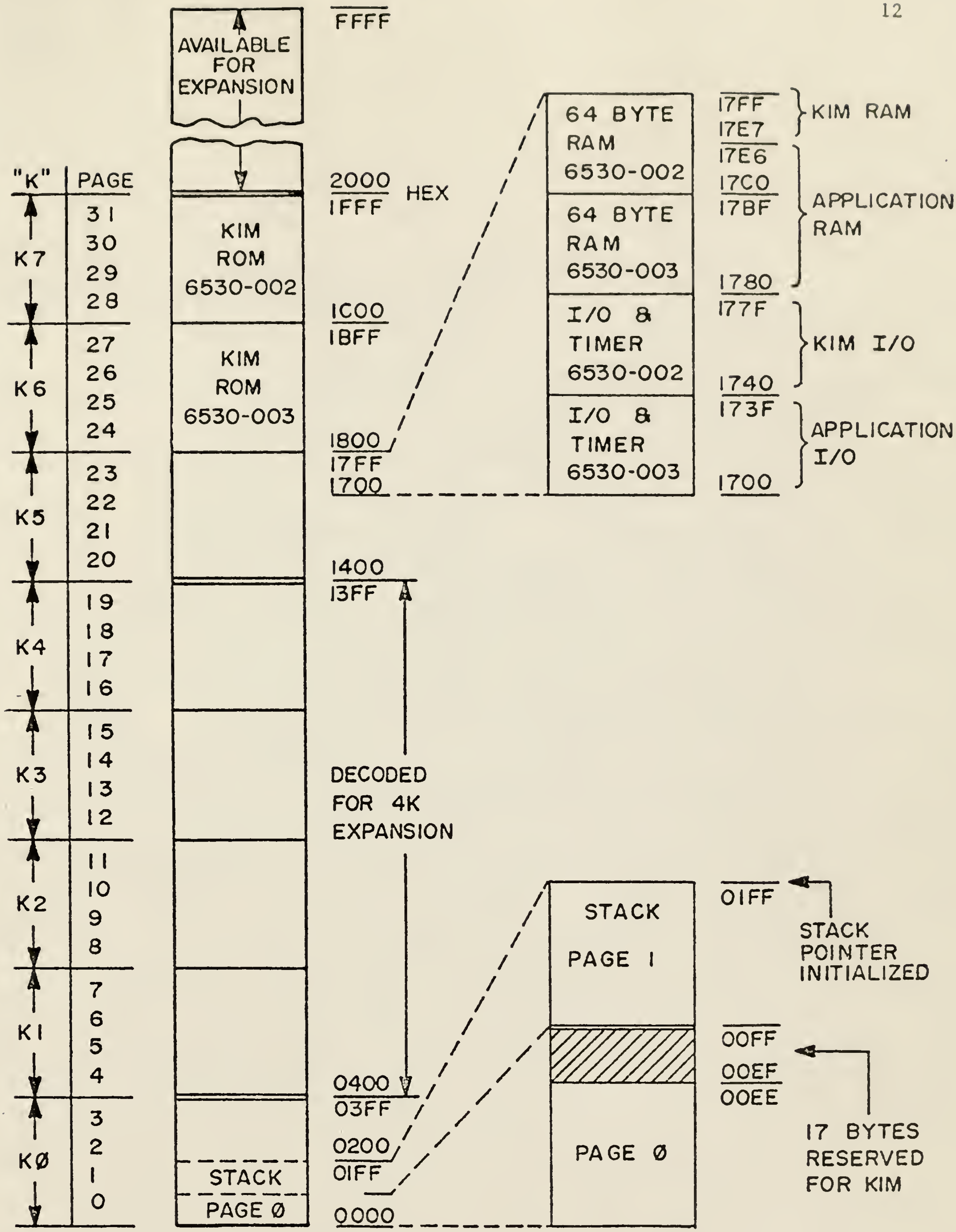


Fig. 2.3-1. KIM-1 Memory Map.

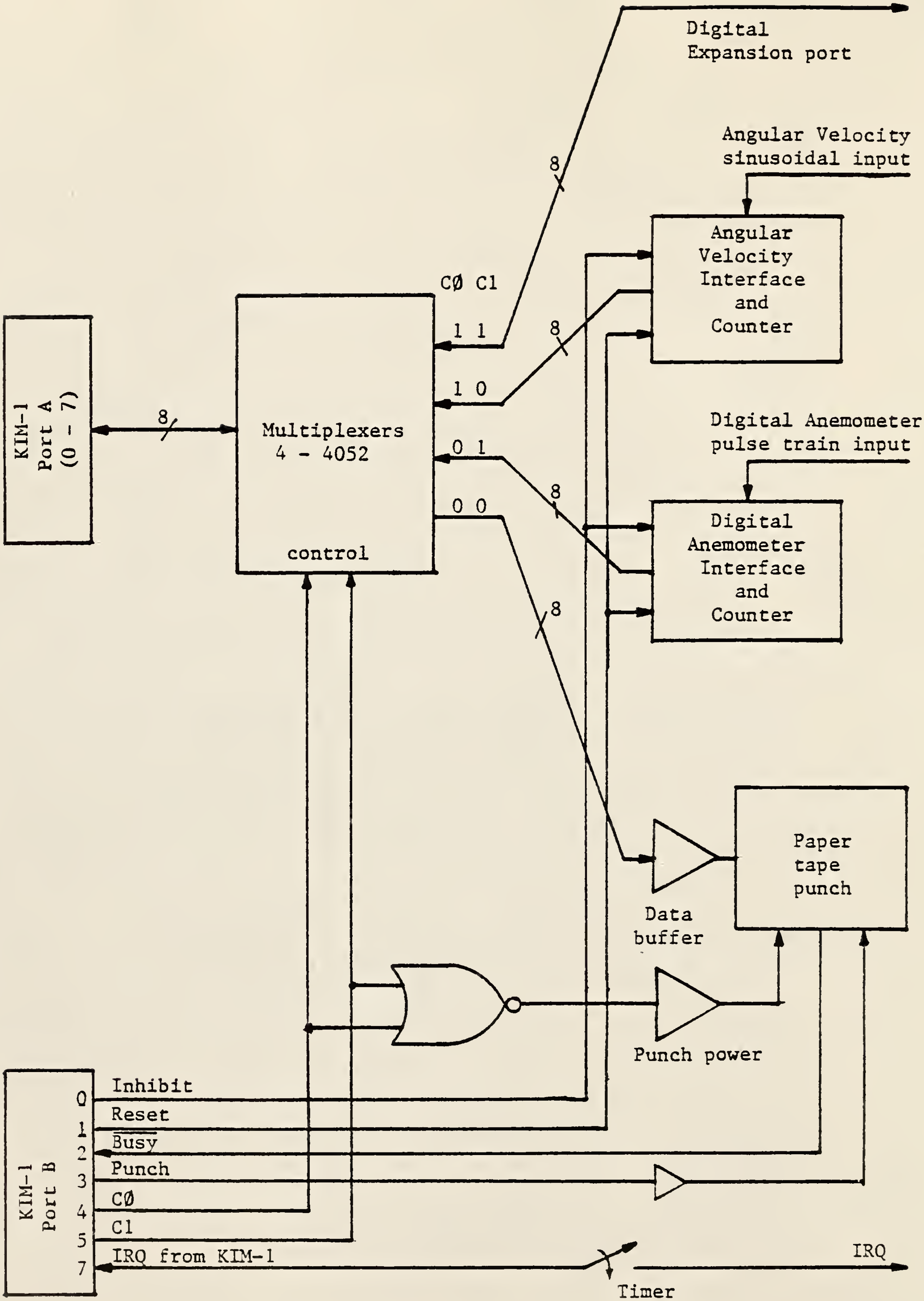


Fig. 2.4-1. Block Diagram of the Multiplexer - Counter Board and Interfacing.

Table 2.4-1. KIM-1 Port B Bit Patterns for Peripheral Control.

Bit		
7	input	IRQ
6	Not available	
5	output	C1
4	output	CØ
3	output	Punch Command
2	input	Busy (punch)
1	output	Reset Counters
Ø	output	Inhibit Counters

Bit # Port B	7	6	5	4	3	2	1	Ø	
	X		Ø	Ø	Ø	1	Ø	Ø	Punch select
	X		Ø	Ø	1	Ø	Ø	Ø	Punch command, Punch busy
	X		Ø	1	Ø	1	Ø	Ø	Angular velocity counter
	X		Ø	1	Ø	1	Ø	1	Inhibit counter
	X		1	Ø	Ø	1	Ø	1	Digital Anemometer counter selected and inhibited
	X		X	X	Ø	1	1	Ø*	Reset counter and release inhibit
	X		X	X	Ø	1	Ø	Ø*	Release reset
	X		1	1	Ø	1	Ø	Ø	Select digital expansion port

*Don't cares (X) in bits 4 and 5 must not be both Ø. This condition will select the punch and power it on.

Figure 2.5-1. The signal from the magnetic pick-up is fed by shielded cable to the input of the multiplexer-counter board. The input is protected against high voltage transients with a gas discharge tube (NE-2), a 1.3kΩ resistor and a 6.8V silicon voltage suppressor (Transzorb [5]). The 1.3kΩ resistor is also used in conjunction with a 0.1 μf capacitor to form a low pass filter. The filtered signal is amplified and shaped by a CA3140 [6] operational amplifier and CMOS 4093 Schmitt trigger. The signal is also gated by the 4093 using bit Ø of port B (inhibit). The angular velocity counter is read by writing a 1 to bit 4 and a Ø to bit 5 of the KIM-1 I/O port B. This condition connects port A to the angular velocity counter through the 4052 multiplexer on the multiplexer-counter board. The counter is inhibited, to reduce glitches, by writing a 1 to bit Ø of port B. After the counter is inhibited a read of port A will yield the contents of the counter. Writing a 1 to bit 1 of port B will reset the counter and a Ø written to bit Ø of port B will release the inhibit. The counter will then count until the next inhibit, read and reset. With the Wind Laboratory system, the angular velocity signal is counted for one-sixth of a second and the angular velocity recorded from these results. The location of the angular velocity transducer in the KSU Savonius wind turbine power shaft yields an output of 423.5 pulses per turbine revolution which produces a count of 1.18 in one sixth of a second per turbine rpm.

2.6 Digital Anemometer

A digital anemometer was developed to overcome problems and errors associated with 'Weather Bureau' type of anemometers. 'Weather Bureau' anemometers are generally analog permanent magnet generators with a

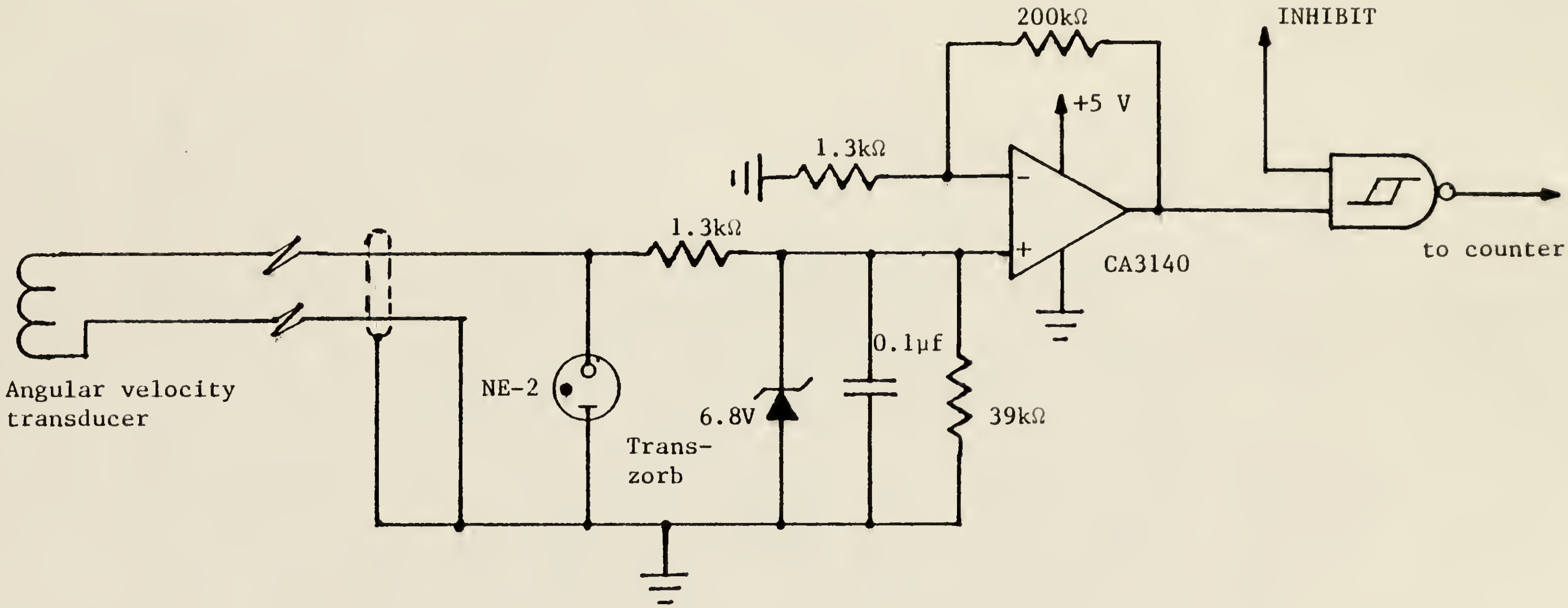


Fig. 2.5-1. Angular Velocity Transducer and Interface. Electronics are located on the Multiplexer - Counter board. Transducer outputs 423.53 pulse per turbine revolution.

cup-wheel assembly. Large errors can arise from the use of these anemometers because of their inherent design. 'Weather Bureau' analog anemometers have a cup-wheel driven armature with a commutator and brush assembly. If the bearings, commutator, or brushes become worn or dirty the output of the anemometer will be lower at equivalent wind speeds. Another problem stems from the fact that all anemometers are averaging devices which act as non-linear low pass filters. The velocity of the anemometer approaches the speed of the wind at the beginning of a wind gust, but due to its mass it overruns and is traveling faster at the end of the gust than the wind. To overcome this second problem, the mass of the anemometer must be reduced. This is done with a pulse rate encoded digital anemometer. The digital anemometer uses a cup-wheel assembly identical to the analog anemometer but reduces the mass of the rotor by eliminating the armature. The cup-wheel assembly on the digital device drives a photo chopper arrangement which outputs a pulse rate proportional to wind speed. The mass of the chopper wheel is small compared to the analog anemometer armature reducing its inertial effects. The first problem is also diminished with the photo chopper arrangement because there are fewer moving parts to get dirty or worn.

The cost of the analog anemometer is also higher than that of the digital anemometer, attributable to its wire-wound armature, brushes and commutator. In contrast, the digital device has a chopper wheel, a light emitting diode, and a photo-transistor or photodiode. This reduces the cost to mainly the cup-wheel assembly and housing. Some problems did arise with the KSU prototype digital anemometer built by Bootman [7]. The major problem with the anemometer was the bearings used on the cup-wheel shaft.

These bearings were standard industrial type sealed ball bearings. Drag factor introduced by these types of bearings were so high that in one case the anemometer did not register until wind speeds reached 3 m/s. Also after prolonged use, the bearing performance deteriorates, making the anemometer unusable for instrumentation purposes.

Improved performance could be obtained by a better choice of bearings similar to the ones used by Electric Speed Indicator Company [8] in their model F420-C wind speed transmitter. These bearings are New Departure SS-7034 and SS-7R4, stainless steel types or equivalents. They are lubricated with a mixture of 2/3 Dow Corning DC-33 silicon grease fluid consistency and 1/3 Hamilton Oil T-3358. Other bearings, especially synthetic ones, might exhibit better results but further development was beyond the scope of this research.

The KSU prototype digital anemometer did produce a 0.4 volt peak to peak sinusoidal signal. This signal was sent by shielded cable to a remote amplifier and counter. However, due to noise and signal level, the system was modified to amplify the signal within the anemometer and send a 0-5 V pulse train to the counter. The 0.4 volt signal produced by the LED-photodiode pair is compared with a 0.2 volt reference by a LM311 voltage comparator. The output of the LM311, pulled to $\pm$5 Vdc with a 21 kΩ resistor, is connected to the input of the multiplexer-counter board via shielded cable. See Figure 2.6-1. The terminating end of the cable at the input to the board is pulled high with another 21 kΩ resistor and protected against lightning by an 8 kΩ resistor-6.8 volt Transzorb pair. The signal is shaped and gated by a CMOS 4093 Schmitt trigger NAND Gate. The pulse train is counted by a 4520 (Dual 4 bit binary counter). See Figure 2.6-2.

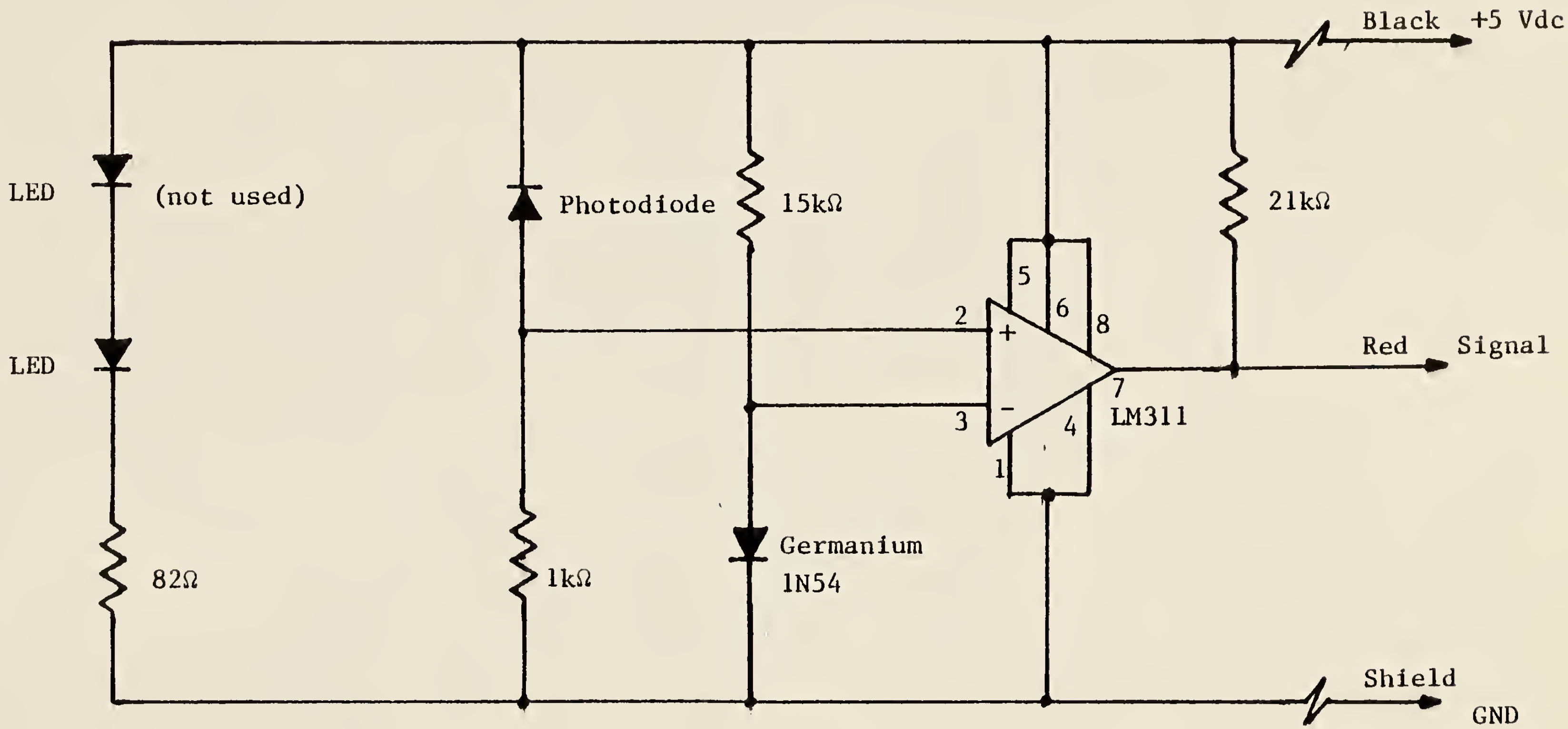


Fig. 2.6-1. Digital Anemometer Photochopper and Voltage Comparator. Components are located in the anemometer housing.

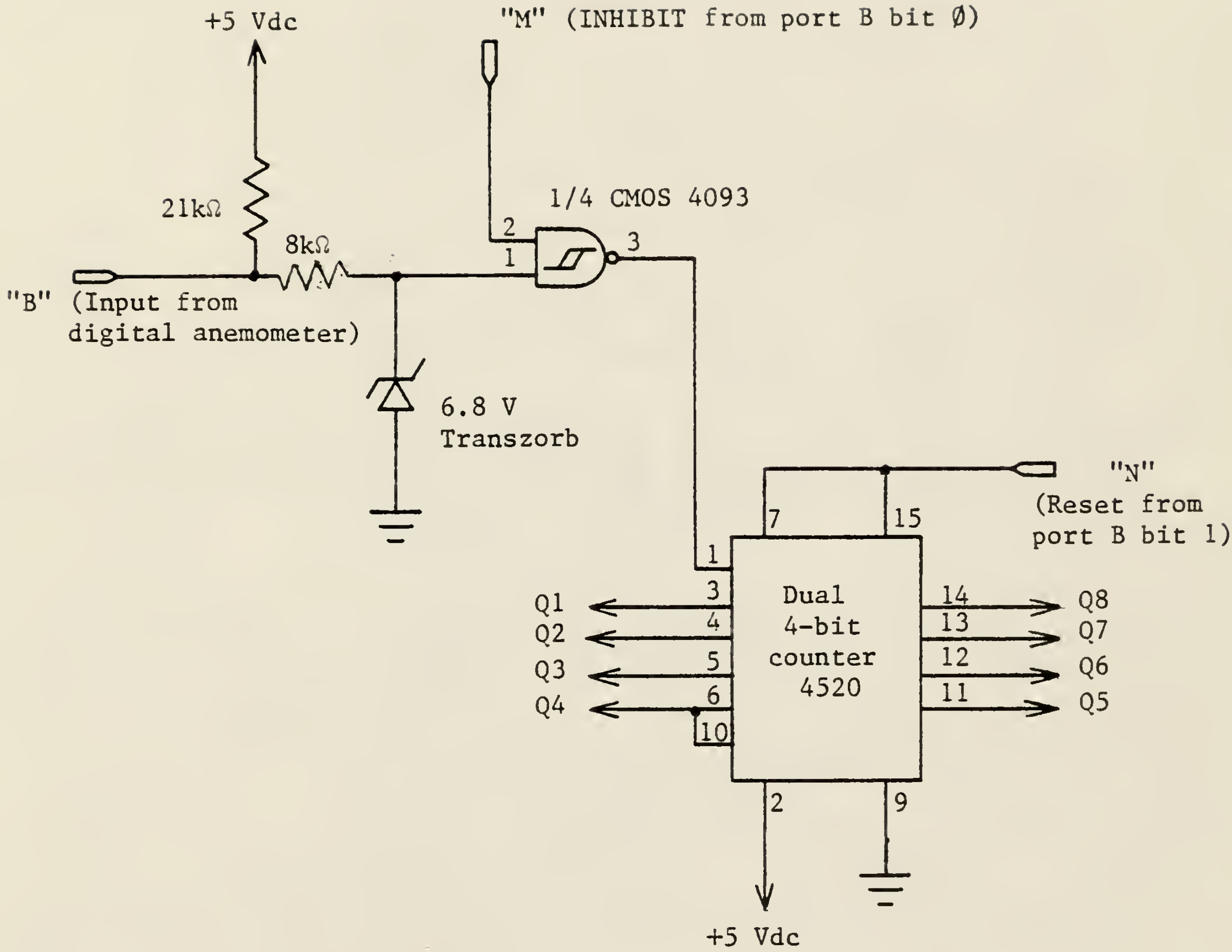


Fig. 2.6-2. Diagram of the KSU Prototype Digital Anemometer Signal Conditioning, Gating and Pulse Rate Counter. Components are located on the multiplexer - counter board.

The digital anemometer counter is read by writing a Ø to bit 4 of port B and a 1 to bit 5. This write connects port A through the multiplexer to the anemometer counter. The counter is inhibited by writing a Ø to bit Ø of port B and the counter contents read by fetching port A. The counter is then reset by a 1 written to bit 1 of port B. Note that both the digital anemometer counter and the angular velocity counter are inhibited and reset by bits Ø and 1 of port B.

2.7 Analog Anemometer

Analog anemometers used at the KSU Wind Laboratory are Electric Speed Indicator Company type F420-C wind speed transmitters. These devices are direct current permanent magnet generators which are self-contained and require no external source of electrical power. With the Wind Laboratory instrumentation system, the fact that the anemometers are self-powered is of little concern, but with a battery powered system, this is of major importance. The output of the anemometer is loaded with a 430Ω resistor, passed through a lightning protection network and fed to the A/D. The input range of the A/D is 0 to 3 volts allowing wind speeds from 0 to 34 m/s (0 to 77 mph). See equation 2.7-1.

Calibration of the anemometer is achieved by driving the armature of the anemometer with a synchronous electric motor and setting the output by adjusting the commutator. With the calibration system used at the KSU Wind Laboratory, the anemometers are driven at 525 RPM with a synchronous motor and the output of the anemometer adjusted to 2.1 volts. With the errors measured during calibration of six anemometers, it is likely that many previous wind records are in error. For example, the output of one anemometer in use for two years was off by a factor of two.

Errors arise from dirty commutator brushes or dragging bearings. The method of calibration given above is quite adequate if the bearings in the anemometer are good. However, if any drag develops from the bearings, the calibration results will be correct, but the field results will be in error. The errors arise from the fact that the driving motor develops enough torque to overcome the bearing effects. Drag related errors are impossible to detect with this calibration method. It would be desirable to have a device to determine the rolling resistance of the bearings. This type of test could be performed in many different ways, but it would be preferable to define one method as a standard. It is suggested to lubricate the bearings once a season and if they are untestable to replace them at the same time. The method of bearing removal and proper lubricants can be found in the Electric Speed Indicator Company F420-C manual.

The six anemometers were tested after calibration for linearity and deviation with the use of the USDA Wind Erosion Laboratory wind tunnel at Manhattan, Kansas. The anemometers were tested with one cup assembly to reduce data variation. The output of each anemometer was loaded with a 430Ω resistor and connected to an A/D input on a Hewlett-Packard Data Acquisition system (Model 2114). The A/D computer system sampled the anemometer and pitot tube assembly 100 times per second and averaged the values over 10 seconds. The test results were quite good with an approximate 1% non-linearity measurement between 2 m/s (4.5 mph) and 13 m/s (29 mph). The absolute error of wind speed at 1 volt output is within 1% and the standard deviation of the anemometers was equal to 0.06 at the 1 volt output level. Another test was performed comparing the output of the anemometers with different cup assemblies. Cup assemblies, 3 new

and one pitted were tested on the same anemometer. The output of the anemometer with the three new assemblies was virtually the same. The pitted assembly, however, had an approximate 2% reduction in output at 10 m/s wind speed.

Data given by the Electric Speed Indicator Company and verified by tests performed in the USDA wind tunnel demonstrated that the voltage across the 430Ω load resistor is described by the following equation:

$$V_0 = \frac{u - 2.3}{25} \qquad (2.7\text{-}1)$$

where u = wind speed in mph

V_0 = output in volts

Electric Speed Indicator Company also gave data for a relationship between wind speed and angular velocity of the anemometer which can be found to be

$$n = 10(u) - 23 \qquad (2.7\text{-}2)$$

where n = angular velocity in rpm

Solving equation 2.7-2 for wind speed and substituting it into equation 2.7-1, yields:

$$V_0 = \frac{n}{250} \qquad (2.7\text{-}3)$$

Equation 2.7-1 is used to compute the wind velocity after data collection and equation 2.7-3 is used for calibration purposes.

2.8 Pressure Transducer

A National Semiconductor Model LX1602A [9] pressure transducer is used to measure atmospheric pressure. This transducer is a hybrid device and is easily interfaced to the A/D microperipheral. See Figure 2.8-1. The device has an overall span accuracy of $\pm 3\%$ with better than $\pm 0.5\%$ repeatability over the rated pressure span. The pressure transducer is limited to a range of absolute pressure between 0 and 103 kPa (0-15 psia).

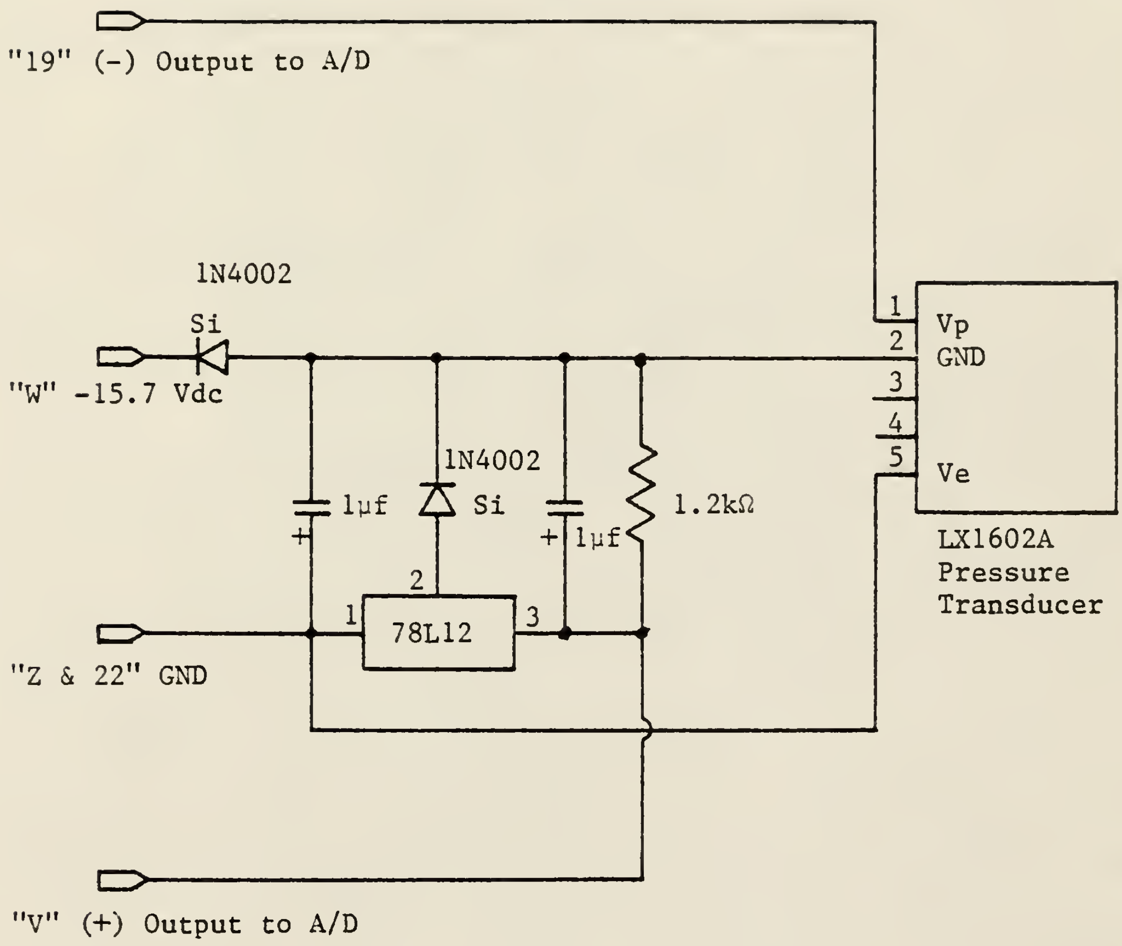


Fig. 2.8-1. National LX1602A Pressure Transducer and Interface Block Diagram.

Another choice of transducer would probably be better in this application because of the transducer's operation close to the uoper end of tis pressure range. This results from the fact that the mean pressure at Manhattan, Kansas, is 98 kPa (14.2 psia).

2.9 Temperature Transducer

A Westinghouse model VT2-841 temperature transducer [10] is used because of its availability and simplicity. This transducer uses a bridge circuit to convert the resistance of a copper detection coil into a voltage. The detection coil resistance is linearly proportional to its temperature over the range of interest. The temperature transducer output is low pass filtered, amplified, and connected to the A/D. See Figure 2.9-1. The accuracy of the transducer is within 2% between 9 and 100°C.

2.10 Wind Direction Transducer

The wind direction is measured by an Electric Speed Indicator [11] model F420-CR2 wind direction transmitter. This transducer is equivalent to a 206Ω potentiometer with the wiper driven by the direction vane. The ends of the resistor are connected to a 3 volt regulated power source. The regulated power supply is necesary because not all direction indicators have the same internal resistance. Regulation is achieved by the use of a transistor, operational amplifier pair as shown in Figure 2.10-1. Shown in Figure 2.10-2 are the connections to the direction indicator and Figure 2.10-3 shows the 5 Vdc reference for the 3 Vdc regulator.

The wind direction indicator arrangement equates both zero and three volts to North. See Figure 2.10-4. The absolute accuracy of the wind direction transmitter is dependent on the linearity of the potentiometer element and was never checked.

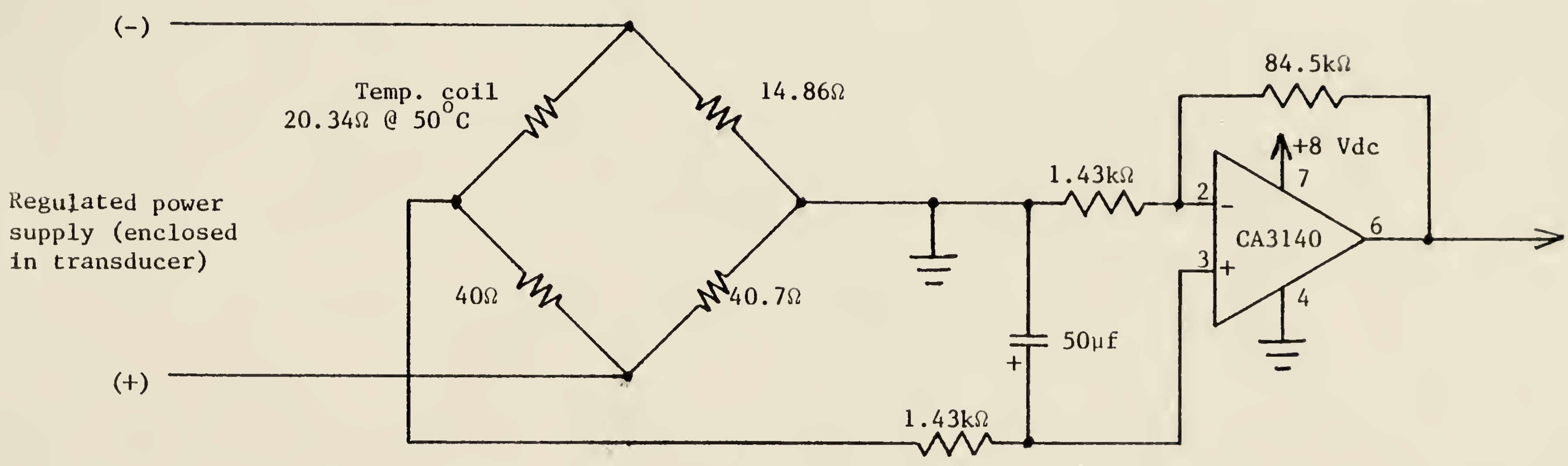


Fig. 2.9-1. Westinghouse Temperature Transducer, Filter and Amplifier Block Diagram. Amplifier is non-inverting with a gain of approximately 60.

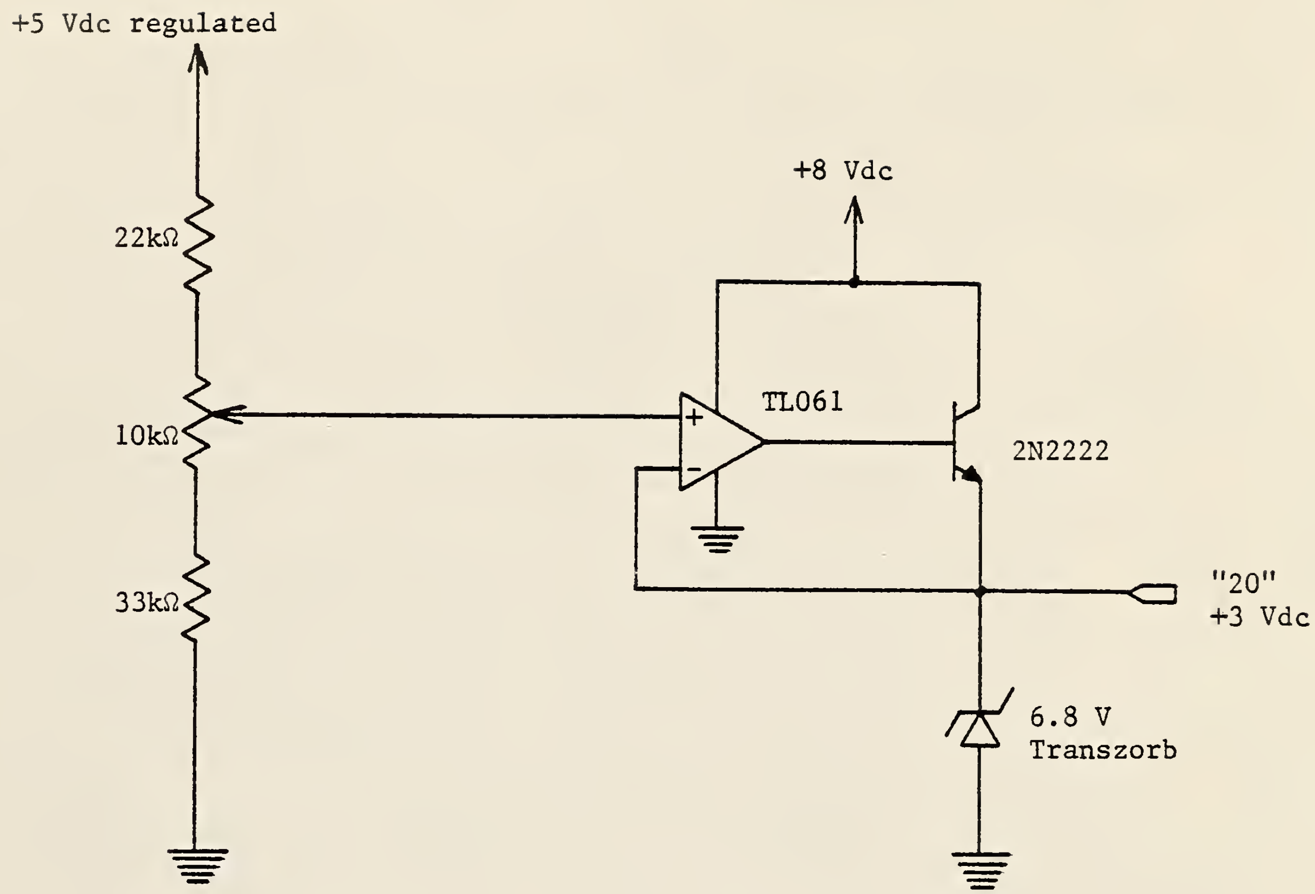


Fig. 2.10-1. +3 Vdc Regulator for Wind Direction Indicator.

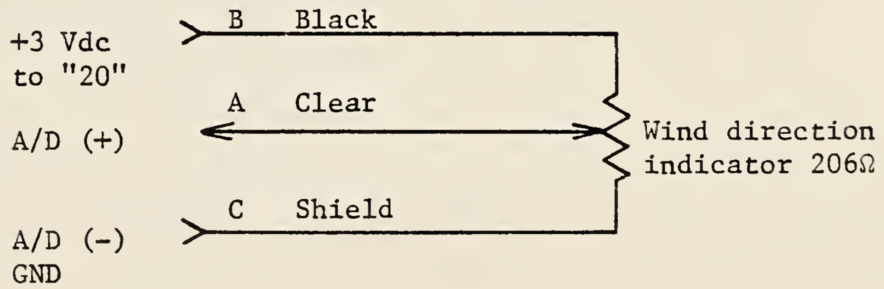


Fig. 2.10-2. Wind Direction Indicator Connections.

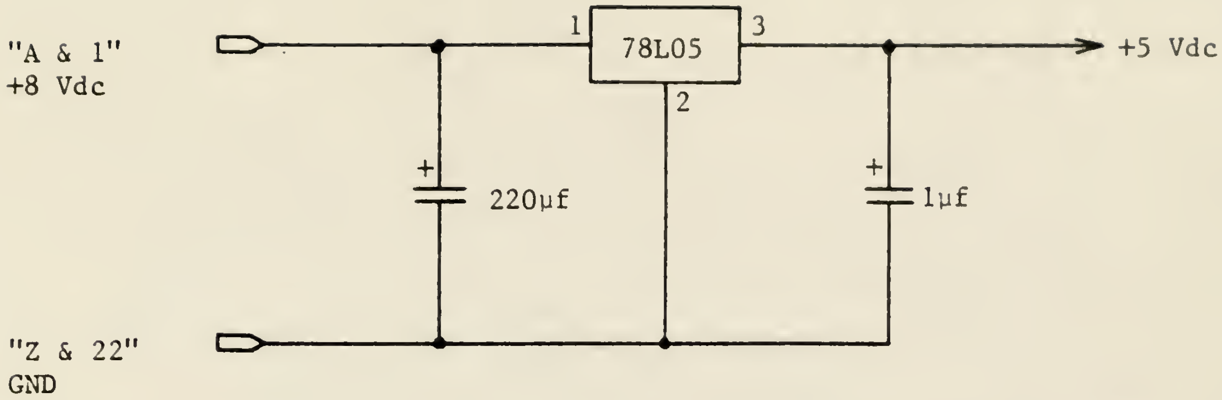


Fig. 2.10-3. +5 Vdc Regulator for Air Pressure - Wind Direction Card.

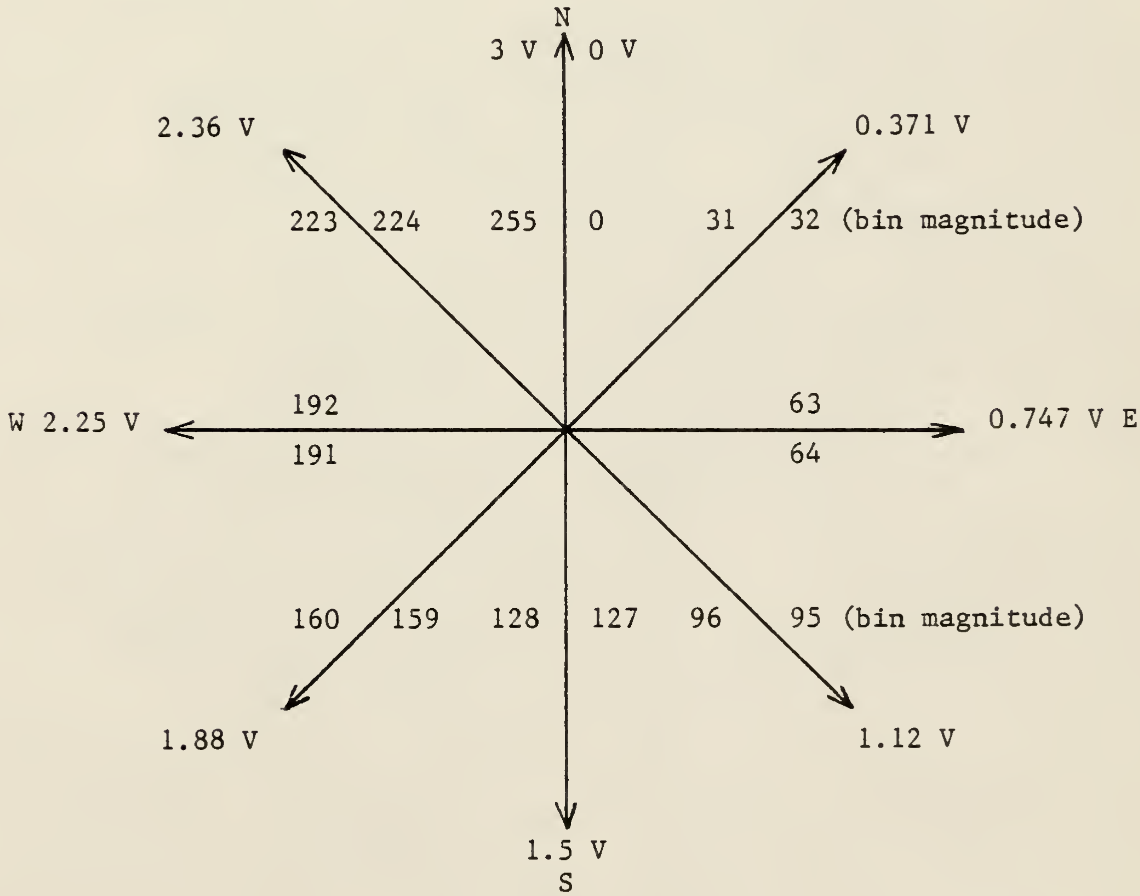


Fig. 2.10-4. Wind Direction Indicator Rose. Output voltage and bin magnitude given.

2.11 Torque Transducer

A Lebow [12] model 1604-1k torque sensor is used for torque sensing in the wind turbine power output shaft. This device employs a power shaft that deforms linearly and in a repeatable manner under a load torque. An array of strain gages are bonded to the power shaft in a Wheatstone bridge configuration. Wheatstone bridge strain gage arrangments inherently compensate for temperature and variations in loading. The strain gage bridge is connected to the secondary of a rotary transformer with the primary of the transformer driven by a Lebow [13] model 7535 strain gage indicator. This indicator generates a 3.2 kHz carrier to excite the sensor rotary transformer. In turn, the sensor modulates the carrier with torque information and returns the modulated carrier to the indicator. The indicator demodulates and filters the signal with a cutoff frequency of 5 Hz. The signal is then amplified and fed to the A/D microperipheral card.

The Lebow strain gage indicator has adjustable gain and the output is set to 3 volts at 1000 in-lb of torque. The torque sensor location in the turbine power shaft is shown in Figure 2.11-1. Torque relationships between the sensor turbine rotor and the sensor alternator, neglecting gear and sprocket losses, are as follows:

$$Tr = \frac{120}{17} Ts$$

$$Ta = \frac{17}{42} Ts$$

Tr = rotor torque

Ts = sensor torque

Ta = alternator torque

With the Wind Laboratory system, the strain gage indicator output is sampled and a bin incremented corresponding to the sampled value. Results of this operation are given in Section 4.4.

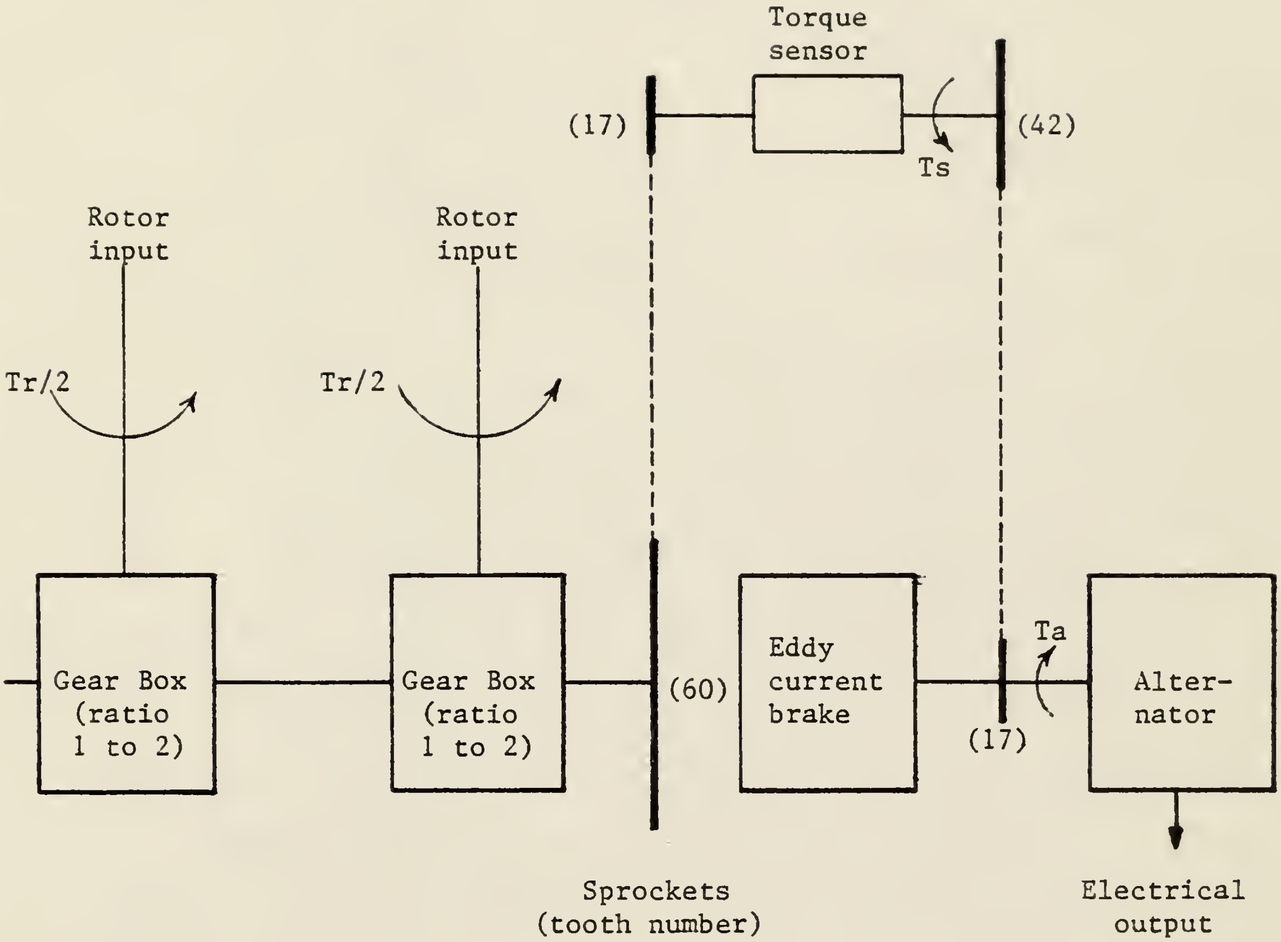


Fig. 2.11-1. Block Diagram of the KSU Savonius Wind Turbine Power Shaft.

2.12 Electrical Power Transducer

The electrical power produced by the Wind turbine is measured with an F.W. Bell [14] model PR-2401SX three-phase watt transducer. This transducer is a 4 wire, balanced voltage device that provides a direct current output proportional to three-phase power. Isolation and the dc output are achieved by use of the Hall-effect. The output of the transducer is 1.0 ma at rated power into a load resistor between 0 and 10 kΩ. A resistor value of 1.78 kΩ was used on the Wind Laboratory system giving a 3 Vdc signal at 6754 watts with the potential and current transformers used. See Figure 2.12-1. With this transducer, accurate measurements of real power to within 0.5% with linearity to within $\pm 0.2\%$ of rated output are attainable. Accuracy deviated as input frequency and voltage varied but was within 1% between 20 Hz and 70 Hz. Below 20 Hz this watt meter was not tested but similar Hall effect transducers were accurate to within 1% as frequency varied to a few Hertz if voltage varied with frequency.

2.13 Alternator Voltage Transducer

A signal proportional to the wind turbine alternator output is obtainable by a three-phase halfwave rectifier circuit. The rectified output is reduced by a resistor voltage divider and fed to the A/D microperipheral card where it is filtered. See Figure 2.13-1. The voltage divider network is an 18.2 kΩ resistor and a 430Ω resistor to give an output of 3 V at 130 V rectified input.

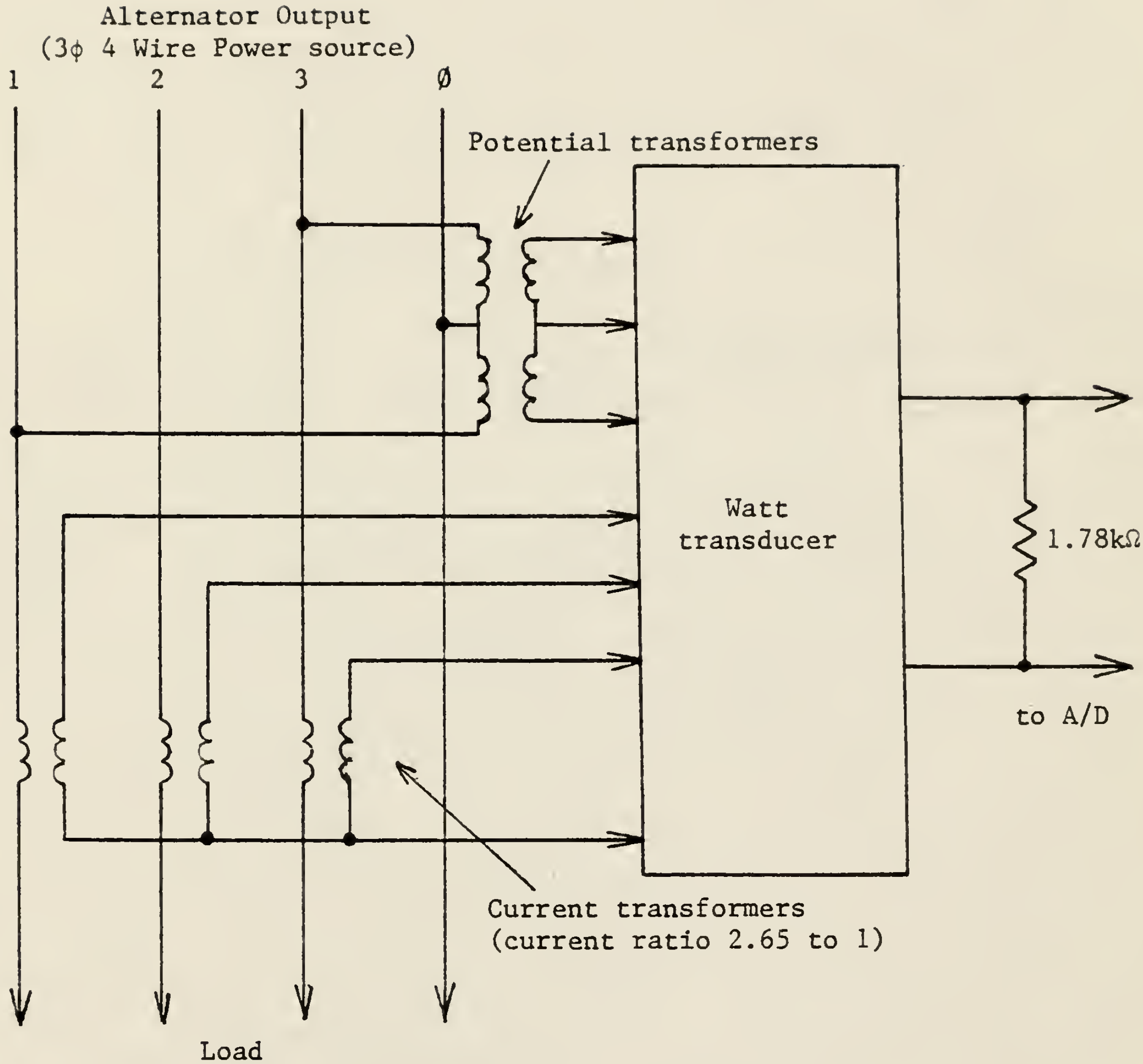


Fig. 2.12-1. Electrical Power Transducer Block Diagram.

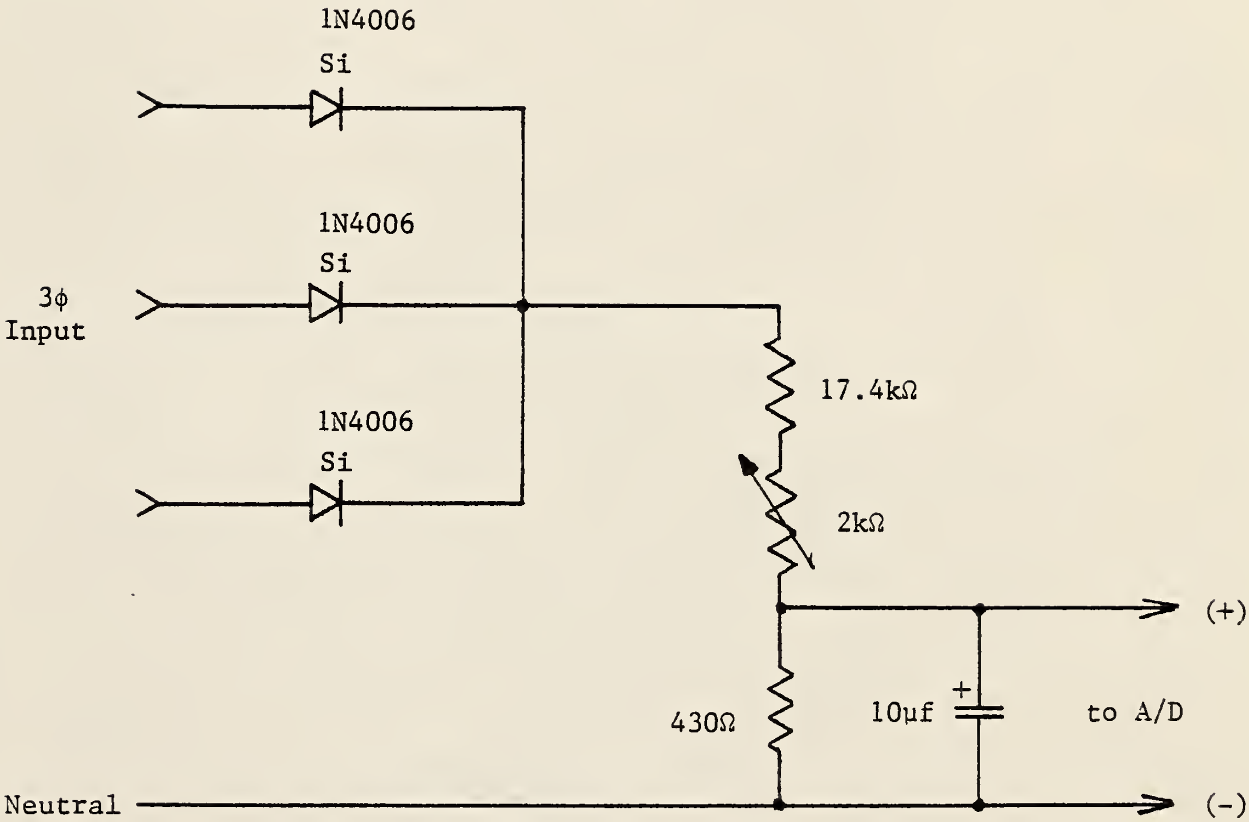


Fig. 2.13-1. Halfwave Rectifier for Alternator Output Voltage Transducer.

2.14 Analog to Digital Converter

Desirable features of an A/D converter for the Wind Laboratory data acquisition system include easy programming, no input-output ports needed on the microprocessor, no external logic, and being completely self-contained.

The Burr-Brown [15] MP21 is such a device with analog inputs and a digital output. The device contains a high speed, eight bit A/D converter, an input multiplexer that can accept up to sixteen single ended or eight differential signals, and an instrumentation amplifier. The block diagram is shown in Figure 2.14-1. The offset and gain are factory laser trimmed so that no external adjustments are required on the ± 5 volt or the 0 to 5 volt input range to obtain an absolute accuracy of better than $\pm 0.4\%$ (1 LSB). Our instrumentation used an input signal of 0 to 3 volts with only the addition of one resistor and a single potentiometer for gain adjustment. By changing the gain, input ranges as low as ± 10 mV can be used.

The MP21 is treated as memory with each analog input channel occupying one memory location. The analog inputs are read with a load or fetch instruction from the processor. Conversion time requirements demand that the address for a given analog channel be read twice in order to get one correct value. The first read addresses the channel, samples the input and starts the conversion. The first read also sets a flip-flop to note that it is the first read. After the required conversion time another read can be made to input data.

The conversion delay is obtainable using four different methods. One is to start the conversion with a read, allowing the MP21 to halt the processor for conversion. When the halt is finished the processor reads

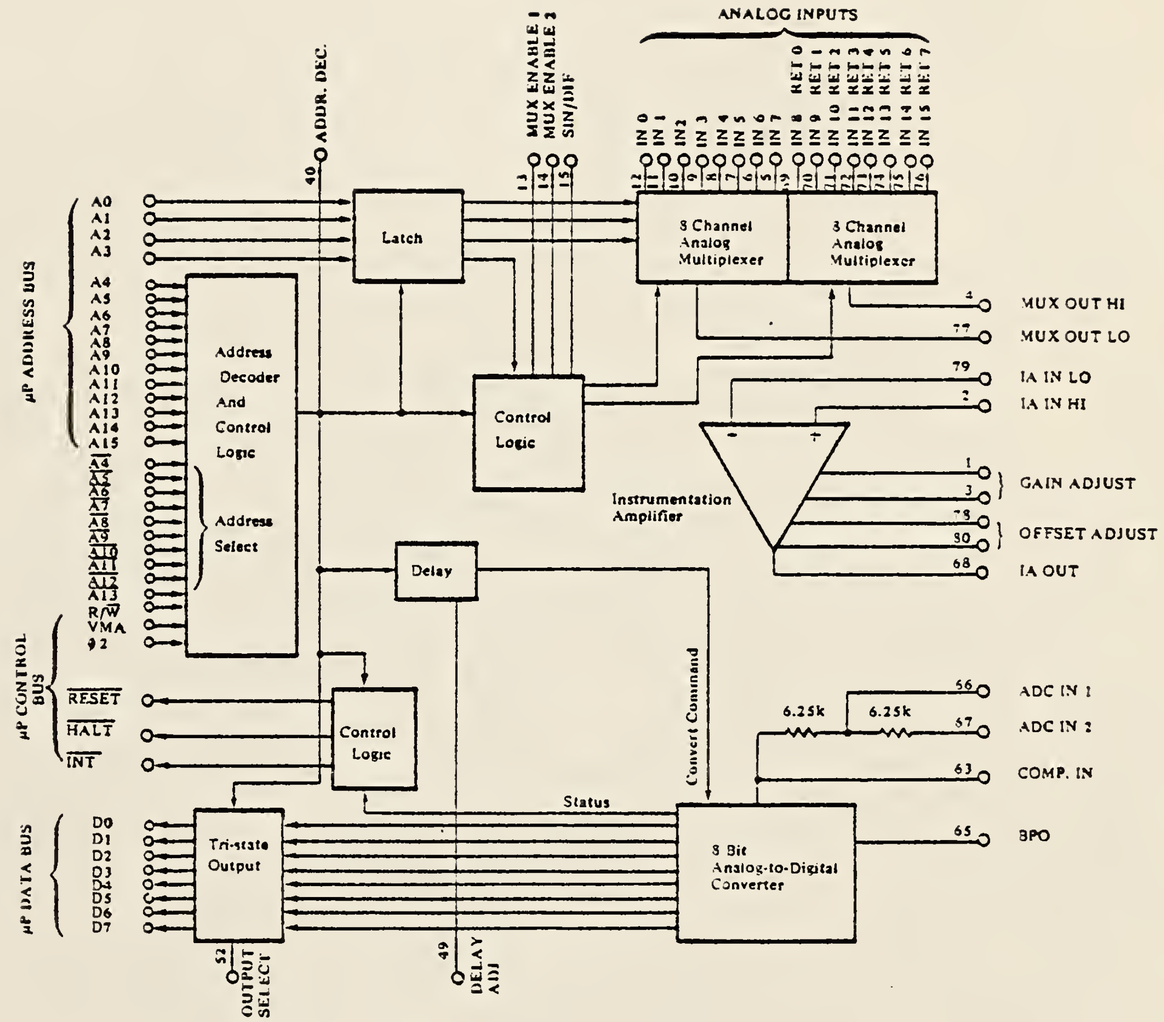


Fig. 2.14-1. MP21 Block Diagram.

the channel to fetch the data. The second delay method is to connect the Halt line of the MP21 to an input port of the processor. Periodically, after the first read, the processor checks the line to detect a complete conversion. When the conversion is complete, the MP21 is read again to obtain the new data. The third method is to connect the interrupt line of the MP21 to the processor. Conversion is started with a read and the MP21 will interrupt the processor when finished. At this point, the data can be fetched. The fourth, and the method used in the Wind Laboratory instrumentation system, is to read a channel and start the conversion. Then a sofware time delay equal to the conversion time is followed by a second read to fetch the data.

Conversion time is a function of amplifier gain, multiplexer setting, and the actual A/D conversion. This time is typically between 40 and 200 microseconds depending upon the gain of the amplifier. Industry tends to use successive approximation A/D's because they offer an excellent compromise between accuracy and speed. The MP21 uses such an A/D with a throughput of 25 kHz per channel. This includes 35 microseconds for multiplexing and amplification and 5 microseconds for A/D conversion. The throughput rate can be increased substantially if an external instrumentation amplifier is used. Burr-Brown, for instance, claims a throughput of 125 kHz per channel with their 3626 high speed amplifier.

The MP21 is directly compatible with the 6800 and 6502 microprocessors. The MP20 performs the same function as the MP21 but is compatible with the 8080 family. Either device can be placed directly on the microprocessor address and data bus; each line is equivalent to one LSTTL load. In general, no external logic is needed because logic levels and timing are microprocessor

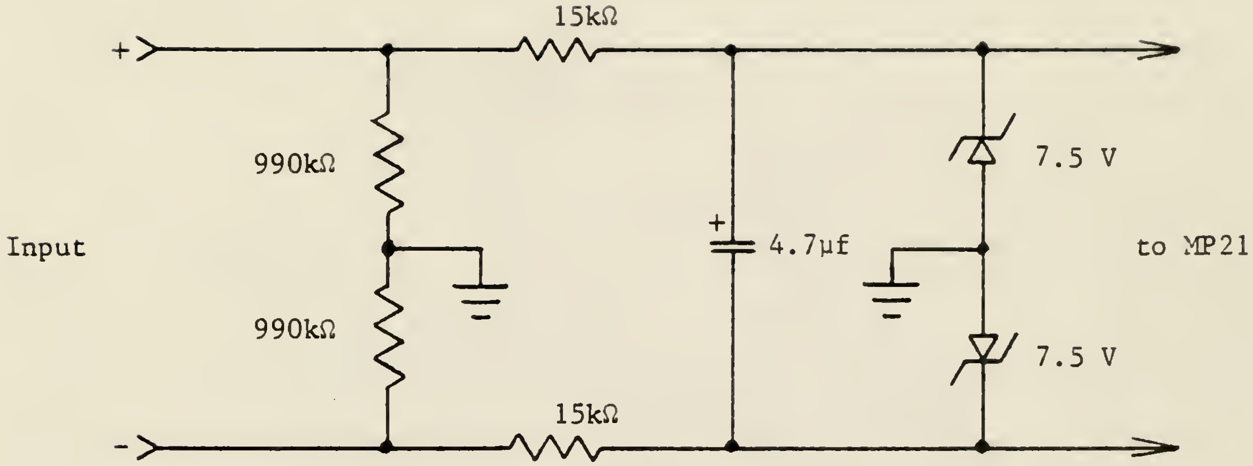
compatible. The MP21 has fully decoded address capability and can lie anywhere above CØØØH without additional gating. On the Wind Laboratory system the two high order bits were inverted for compatibility with the KIM-1. The KIM-1 is decoded for addresses below 1FFFH. The memory map for the MP21 is given in Table 2.14-1. Edge card connections and MP21 connections are given in Appendix C.

Table 2.14-1. MP21 Memory Map

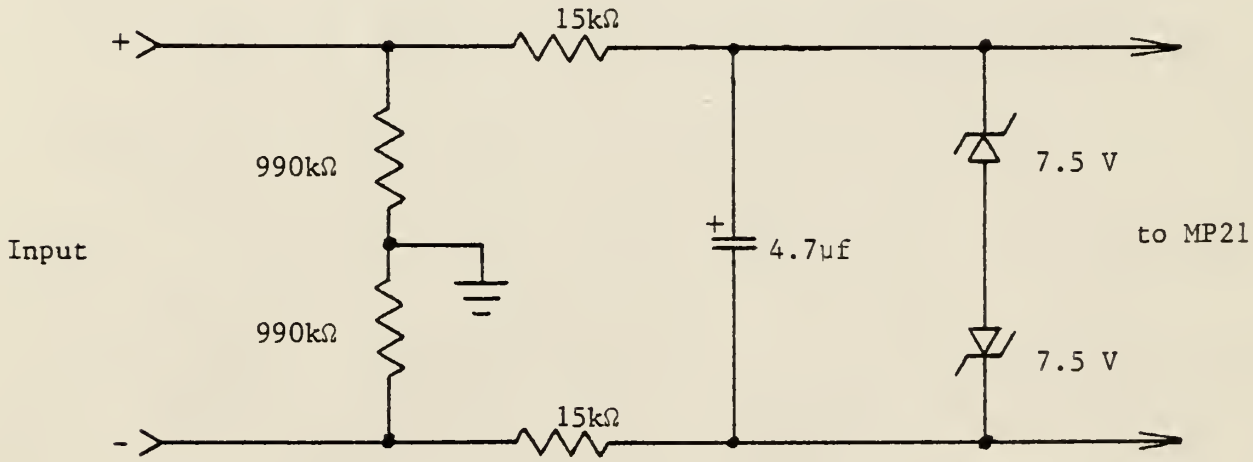
Analog Channel	Address
1	14ØØH
2	14Ø1H
3	14Ø2H
4	14Ø3H
5	14Ø4H
6	14Ø5H
7	14Ø6H
8	14Ø7H

The power requirements for the MP21 are ±30 and 90 mA at ±15 and 5 Vdc, respectively. The device when first viewed is an impressive 80 pin package, but the application and use of the MP21 is very simple and straightforward. After deciding on the mode of operation, and connections have been made to the address bus, data bus, control lines, power and analog inputs, the MP21 is ready to work.

The analog inputs are internally protected by reverse biased diode circuits against over voltages up to ±23 V. External protection is added by means of series resistors and Zener diodes. See Figure 2.14-2. The external diodes also protect the input from damage by static; however,



All channels except channel 7



Channel 7

Fig. 2.14-2. Input Protection for A/D (MP21).

static precautions should still be observed. Neither the internal diodes nor Zener diodes protect against lightning. The MP21 will work without difficulties over a wide range of input voltages. Typically, these voltages are between ±10 mV to ±5 V.

Problems arising with the MP21 were few. However, one problem that developed was that the 6502 does not have a Valid Memory Address (VMA) line. To compensate for this, the VMA line on the MP21 was tied high. In this mode of operation, everything operates properly unless the Halt capabilities are also used. The Halt feature is such that after a read of the MP21, the MP21 pulls the Halt line low. This stops the microprocessor for 40 microseconds, allowing for settling and conversion. Since the address lines on the 6502 are still valid, the MP21 decodes and starts conversion every other clock cycle. This decoding keeps the Halt line low and the processor is latched in the halt state. Writing a software loop of 40 microseconds avoids the use of the Halt line and also allowed the interrupts to be serviced at any time.

Another problem--and a very major one in outdoor work--is lightning protection. With wind turbine instrumentation, the input of the MP21 must be protected against lightning and transients. The proposed method is a series resistor and a parallel transient suppressor.

2.15 Lightning Protection

Any instrumentation system used in the out-of-doors is subject to lightning and its induced transients. Protection against lightning can be accomplished by many different methods.

Active lightning protectors typically come in three types of devices: crowbar, constant voltage, and combinations of these [16]. A crowbar

device will effectively become a short to ground when the input voltage exceeds some value and remain shorted until the current drops to a low level. On the other hand, a constant voltage device will conduct very heavily when the voltage rises above a specified level and below this level the device conducts very little.

Common constant voltage devices used today are Zener diodes, varistors, and silicon voltage suppressors. These devices will all accomplish the same function, but vary significantly with respect to response time. A lightning induced voltage can rise to thousands of volts in a few microseconds. Therefore, it is important to select a device with an extremely fast response time. The silicon voltage suppressor has this feature.

Gas discharge tubes and spark gaps are the most widely used crowbars. To obtain a low cost device with fairly constant striking voltage, standard NE-2 neon lamps can be used. These lamps break down and ignite at approximately 80 Vdc and will conduct a few milliamperes of current until the lamp extinguishes at about 60 Vdc. At voltages above 170 Vdc, the lamp allows extremely large amounts of current to flow. Currents of these magnitudes will destroy the lamp if allowed to flow for more than a few microseconds; however, with lightning this is of little concern.

Combinations of neon lamps, 1.4 kΩ resistors and 6.8V silicon suppressors were used to protect the A/D inputs on the Wind Laboratory instrumentation system. The arrangement is shown in Figure 2.15-1. The A/D used in this system has differential inputs with input impedances of approximately 5 gigaohms. Therefore, the additional impedance of the resistor is of little importance. The resistance in this circuit can be

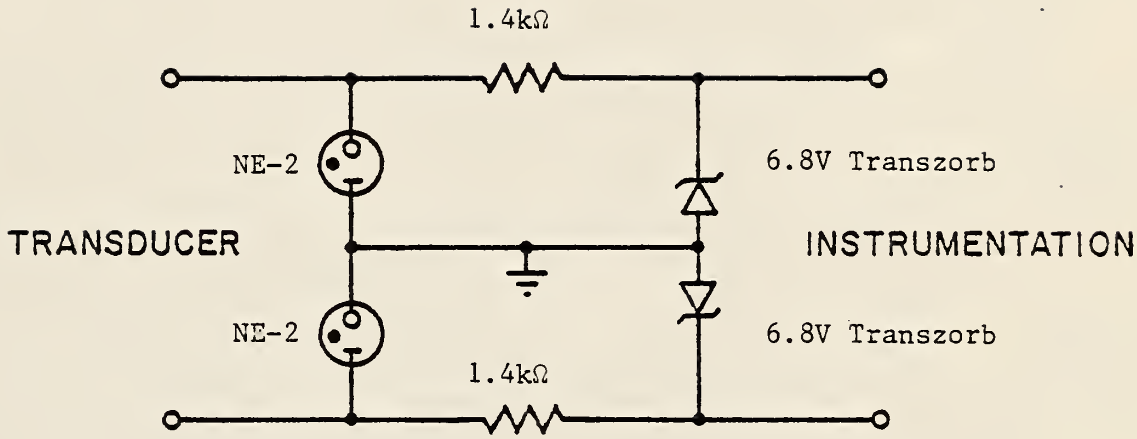


Fig. 2.15-1. Lightning Protection Circuit.

replaced by an inductor if the dc resistance is intolerable. The combination used eliminates impluse spikes, allows large fault currents to flow yet maintains a safe voltage at the output.

Power supply protection is also necessary to ensure that voltage transients do not damage the instrument. One of the simplest methods of providing protection is a battery placed in parallel with the power supply as a buffer.

None of these systems will provide protection against a direct hit, which will destroy the instrument. They will, however, protect against near misses.

Another possible method of protecting wind instruments from lightning is the use of light-coupled transducers. For anemometers, this would entail a fiber optic channel from a light source in a protected environment to the anemometer. The anemometer would interrupt the light with a chopper wheel and return the information through another fiber optic channel to a photo sensor in the protected instrument. A similar type arrangement could be utilized by a wind direction indicator employing a gray code. With fiber optics being the only exposed information channel, lightning problems would essentially be eliminated. Power consumption of the fiber optics system is not large, but may be substantially larger than the power requirements of a CMOS microprocessor. This would be an important consideration in a battery powered wind instrumentation system.

2.16 Calibrations and Errors

Errors can arise in any instrumentation system from many sources. It is of utmost importance to achieve a system that can be used with

complete confidence. The only way to gain this confidence is careful calibration of each transducer and of the instrumentation system. With the Wind Laboratory system, each transducer was calibrated by methods given in their appropriate sections. The A/D was calibrated by a standard 1 volt cell and the pulse rate counters by a signal generator and frequency meter. Calibration must be done regularly to ensure quality data. Some possible errors can be reduced by proper design and the use of high quality devices such as instrumentation amplifiers.

3. SYSTEM SOFTWARE

3.1 Introduction

Software is given for two different modes of operation. The first mode of operation is binned data acquisition, and the second mode is sequential data acquisition. The sequential data acquisition program samples all of the transducers 6 times per second for 256 samples each. These sampled values are stored in memory and punched on paper tape after complete acquisition. The binned data acquisition system samples each channel 6 times per second and increments a memory location corresponding to the magnitude of the sampled value and its channel number.

The software is divided and written as subroutines for ease of programming. Subroutine and the main program flow charts are given in Appendix E and the cross-assembled code in Appendix F. The flowcharts and programs are hopefully self-explanatory and therefore little discussion is given here. However, generalized flow charts are provided in the following sections to allow an overview of the system software.

3.2 MOS Technology Cross-Assembler

To allow ease of programming an MOS Technology cross-assembler was used to assemble the programs. The KIM-1 program is punched on standard IBM cards by using the format given in the cross-assembler manual. The punched cards are fed to the computer with the proper job control cards [18] to route the cross-assembler output to a user available file. The file produced by the cross-assembler includes much unwanted output. Techniques given by the KSU CMS Manual [19] can be employed to delete the

unwanted output. The output needed is type ';3'. This type of output is in the form ;3, 8 spaces, starting address, space, 16 bytes of data, space and 2 bytes of checksum. Everything punched following and including the first line of type ';3' data is the program. The program is retrieved on paper tape by use of a modem and TTY (see details in the CMS manual). The program given in Appendix D will load the cross-assembled paper tape into the appropriate memory locations.

3.3 Binned Data Acquisition

The complete software to control the instrument is given in detail in Appendices E and F. However, a brief explanation of the system is given here with the aid of the generalized flow chart shown in Figure 3.3-1. After power-up, the processor idles, checking the keyboard. A user selected channel (key) will display that channel's most recently sampled value. At regular intervals, the timer will interrupt the processor which in turn resets the timer, updates the calendar and collects new data. Data collection is performed as two reads or fetches from the microperipheral. The first read starts the conversion and, after an appropriate wait, the second read fetches the data. The collected data byte is used as an address to increment the appropriate bin. After complete data collection, the processor will return to the display routines. If any bin is full, the processor will output the complete data file including time, date, and checksums to the paper tape punch.

An appropriate sampling rate must be chosen to sample the transducers and give reconstructable results. The analog anemometers have the fastest usable response time. Selecting the sampling rate to accommodate

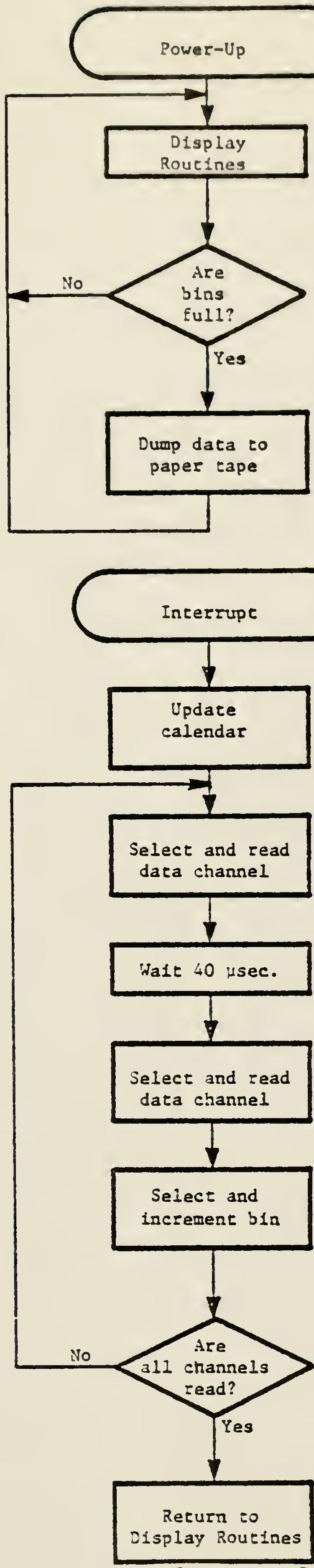


Fig. 3.3-1. Generalized Operating Schemes for Data Collection.

these anemometers will ensure that the sampling period is shorter than all other time constants of the wind turbine system. Analysis given by Bootman indicates that a sampling frequency of 1 to 4 samples per second would be adequate to reconstruct the original signal. Because of programming ease, a sampling frequency of 6 Hz was chosen. The analog inputs of the A/D board are low pass filtered to a 1.2 Hz cutoff frequency. With this cutoff frequency, sampling rates as low as 3 Hz can be made without a frequency aliasing problem. There is some question whether aliasing can be considered a problem with binned data sampling and needs further investigation.

3.4 Sequential Data Acquisition

The sequential data acquisition routine samples the transducers 6 times per second and records the sampled value in order of sampling for 256 samples of each transducer. A generalized flow chart is shown in Figure 3.4-1. The machine is initialized for one-sixth of a second interrupts and the channel count set to zero. After an interrupt to wait for 1/6 of a second, both digital channels and all 8 analog channels are read. Upon the collection of 256 samples from each channel, the computer jumps to the output routine of the binned data program and punches the data on paper tape.

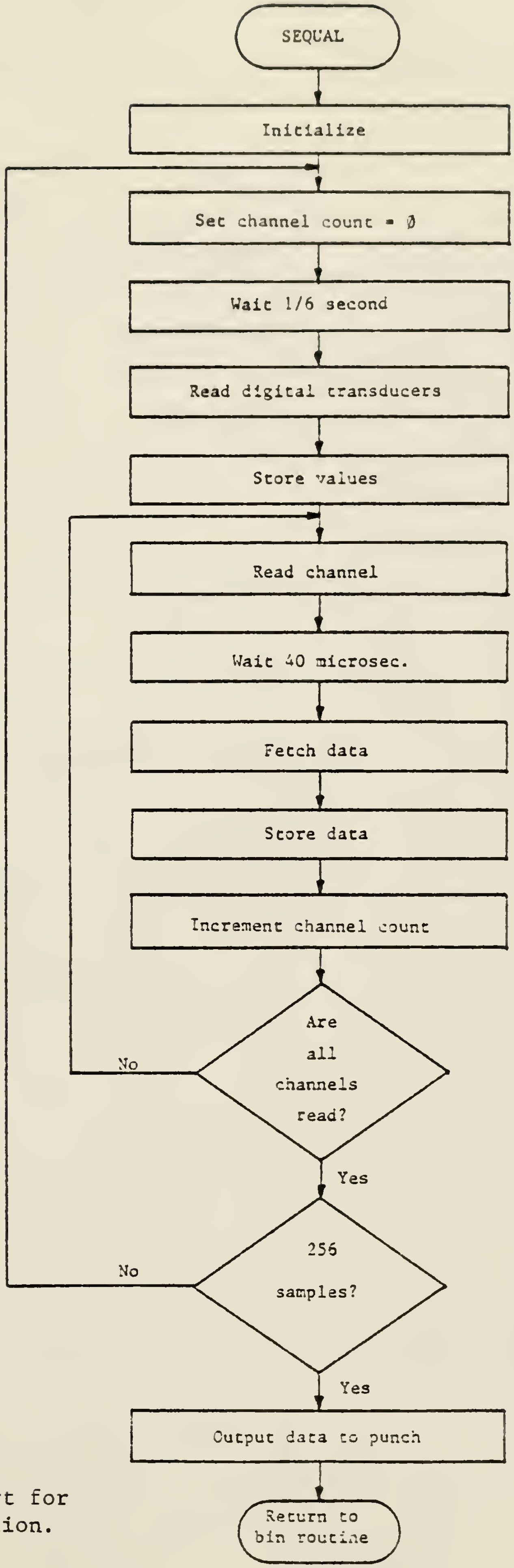


Fig. 3.4-1. Flow Chart for Sequential Data Collection.

4. SYSTEM OPERATION

4.1 Introduction

System operation is both simple and straightforward. System programs are recorded on audio cassette by methods given in the KIM-1 user manual. For operation the system is powered-on with $\pm$15.7 Vdc, $\pm$12 Vdc and +5 Vdc. The +12 Vdc is only required for the audio cassette operation. After power-on, the system program is loaded into the system memory. See Appendix A for deatils. Once the system program is loaded, the user must initialize time, date and mode of data collection. There are three types of data collection - binned data above angular velocity threshold, binned data and sequential data. In the binned data above angular velocity threshold mode, the transducers are sampled 6 times per second and the information built into a histogram only when the turbine's angular velocity is above a specified level. If the turbine's angular velocity is not great enough, the transducers are not sampled nor the bins incremented. The binned data mode functions the same as the binned data above angular velocity threshold mode only with a zero threshold. In either bin mode, data can be viewed while the system is running. Viewing is accomplished by the user selecting the channel of interest with the appropriate key. This operation displays in the KIM-1 address field, the last value the system sampled from the channel selected. A table of the channel numbers and their corresponding transducers is given in Appendix C.

In the binned data modes, the calendar does not update to a new year and must be done manually. It should also be noted that the delta wind speed is derived from positive changes in wind speed from the digital anemometer.

The sequential mode collects data in an ordered manner at 6 samples per second and stores the data in the microcomputer memory. After 256 consecutive samples are taken, the system dumps the data on paper tape and returns to the binned data mode. See Appendix G for detailed operations.

4.2 Memory Allocation

The microcomputer memory space is divided into regions for data, program, stack and temporary storage. Each transducer and computed value, such as mechanical power, has one page of memory reserved for data between Ø8ØØH and 13FFH. See Table 4.21. These locations are used for both sequential data and binned data acquisition modes. Locations between Ø2ØØH and Ø7FFH are reserved and contain the system program. Temporary storage locations are on page zero and the processor stack is confined to page 1.

4.3 Paper Tape Format

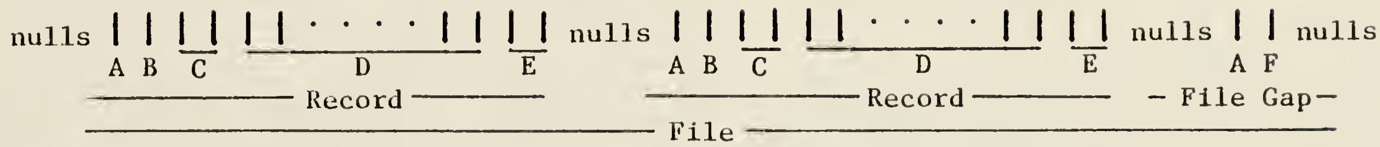
Data are collected and ordered in bins from Ø to 255. However, data are punched on paper tape in reverse order, high bin through low bin (i.e., bin 255, 254, 253,...,2, 1, Ø). The punch format is given in Figure 4.3-1 and is in the form of sync character, record type, number of data points, data and a two-byte checksum. After all records have been punched, a record type zero is punched to indicate end of file. An example time record is given in Figure 4.3-2, and record numbers which correspond to channel numbers are given in Table 4.3-1.

4.4 Data Reconstruction

All transducer values collected with the method of bins are mapped into a range or distribution. This range is defined as the bin width. The KSU Wind Laboratory system has 256 separate bins in which the span of

Table 4.2-1. System Memory Allocation

Address Page (Hex)	
13ØØ	Anemometer (Analog) #1
12ØØ	Torque
11ØØ	Electrical Power
1ØØØ	Alternator Voltage
ØFØØ	Wind Direction
ØEØØ	Air Temperature
ØDØØ	Air Pressure
ØCØØ	Anemometer (Analog) #2
ØBØØ	Angular Velocity
ØAØØ	Digital Anemometer
Ø9ØØ	Delta Anemometer
Ø8ØØ	Shaft Mechanical Power
Ø7ØØ	Program
Ø6ØØ	"
Ø5ØØ	"
Ø4ØØ	"
Ø3ØØ	"
Ø2ØØ	"
Ø1ØØ	Stack
ØØØØ	Temporary Storage



A ASCII Sync character (16H)

B Record type (non-zero)

C Number of points (16 bits, high byte low byte)

D Data (b bits) bytes punched in reversed order

E Check-sum (16 bits, high byte, low byte)

F Record type = Ø (indicates end of file)

Fig. 4.3-1. Paper Tape Format.

nulls	sync	DH	Ø	9	year	last min.	last hour	last day low byte	last day high byte	present min.	present hour	present day low byte	present day high byte	2 byte check-sum	nulls

Fig. 4.3-2. Example of Time Paper Tape File.

Table 4.3-1. Output Record Type

Record Number Dec	Hex	
∅	∅	End of file
1	1	1 - Analog anemometer
2	2	Torque
3	3	Electrical Power
4	4	Alternator voltage
5	5	Wind direction
6	6	Air temperature
7	7	Air pressure
8	8	2 - Analog anemometer
9	9	Digital anemometer
1∅	A	Delta wind speed
11	B	Angular velocity
12	C	Shaft mechanical power
13	D	Time

the transducer is mapped. To properly reconstruct the transducer information some estimations must be made. All analog transducers used in the KSU system map a 3 volt signal range into the 256 bins as shown in Figure 4.4-1. Plotting a straight line through the center of the range yields a line 'A' and the following equation:

$$V = \frac{3 - \frac{3}{256}}{256} V' + \frac{3}{2(256)} \qquad (4.4\text{-}1)$$

where V = output voltage

V' = bin number.

Equation 4.4-1 will yield results for all binned data taken with analog transducers. For the analog anemometer equation 2.13-1 yields:

$$u = 25\ V_0 + 2.3 \qquad (4.4\text{-}2)$$

where u = wind speed (mph)

V_0 = output voltage.

Equation 4.4-1 and substituting into equation 4.4-2 gives:

$$u = 25 \left(\frac{3 - \frac{3}{256}}{256} V' + \frac{3}{2(256)}\right) + 2.3 \qquad (4.4\text{-}3)$$

From information given in Section 2.11 on the torque transducer, it is known that with a torque of 112.99 Nm the output of the torque meter will be 3 V. This information and equation 4.4-1 yields the following results for turbine torque:

$$T = \left(\frac{3 - \frac{3}{256}}{256} T' + \frac{3}{2(256)}\right) 37.66 \qquad (4.4\text{-}4)$$

where T = Torque at sensor (Nm)

T' = bin number.

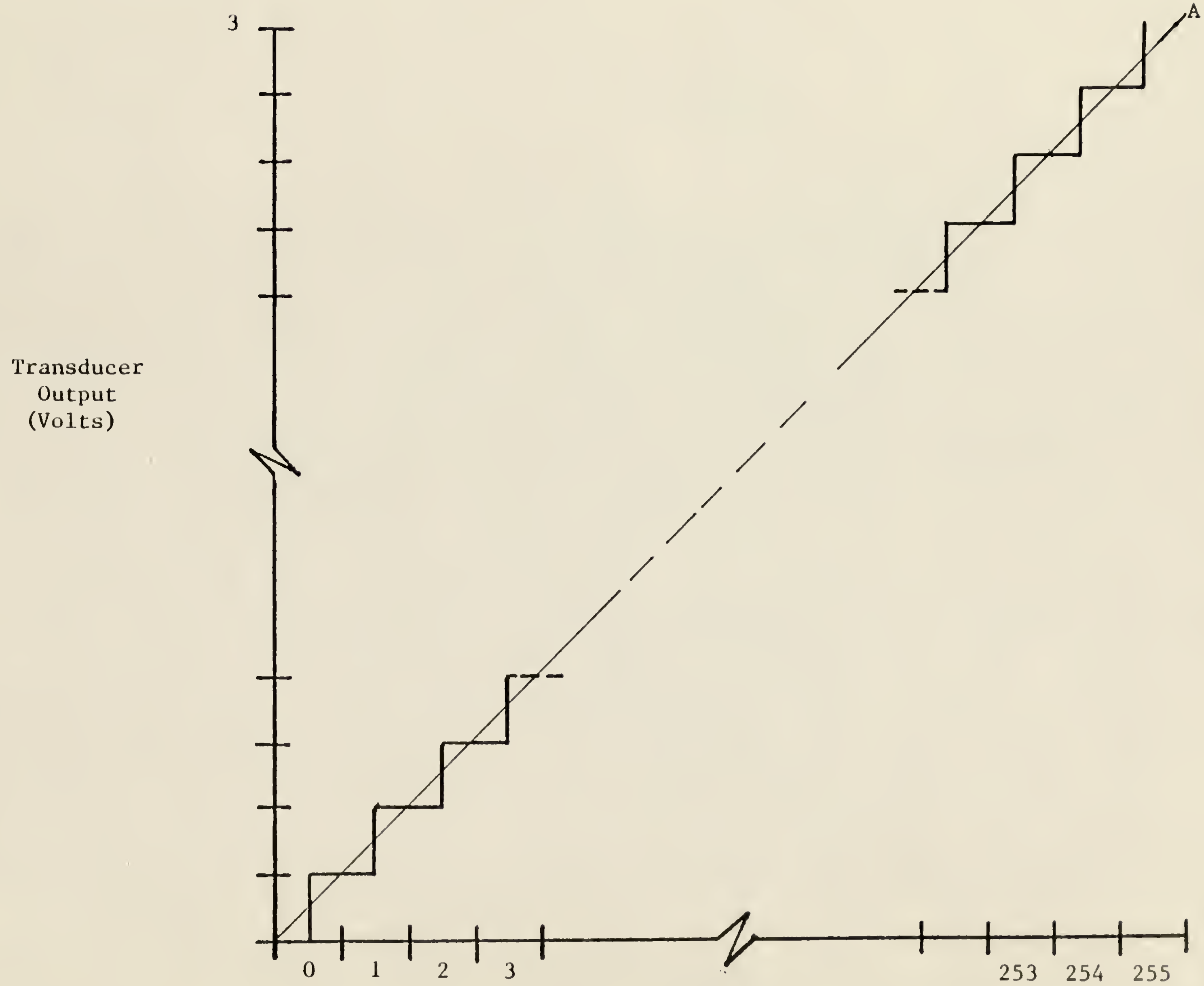


Fig. 4.4-1. Analog Transducer Output Mapped into Bins.

By following the above examples, relationships can be found for any analog transducer using the method of bins. Similar results can be found for the pulse rate transducers. For instance, it is known that from the angular velocity transducer

$$\omega_s = \frac{\pi}{5}\,\omega'' \qquad (4.4\text{-}5)$$

where ω_s = angular velocity at the transducer (rad/sec)

ω'' = sampled value.

The angular velocity values are also mapped into a range as shown in Figure 4.4-2. Equation 4.4-5 is also shown as line B. Upgrading the line to the center of each range or bin (line C) yields

$$\omega = \frac{\pi}{5}\,\omega' + \frac{\pi}{10} \qquad (4.4\text{-}6)$$

where ω' is the bin number.

To obtain a mechanical power value from the turbine, the instrumentation system does a multiplication of the sampled angular velocity (ω') and the sampled torque (T'). From equations 4.4-4 and 4.4-5 and Figures 4.4-1 and 4.4-2, it can be seen that this multiplication is a low or conservative value of the power product. See line F, Figure 4.4-3. To get a better value, the system does a $T' + 1$, $\omega' + 1$ multiplication (Figure 4.4-3, line E) and adds the results to the T', ω' multiplication. However, only the high byte of addition is recorded, which is equivalent to a division by 256. To reconstruct the appropriate power value use equation 4.4-7. See line D, Figure 4.4-3.

$$P = 35.49\,P' + 17.75 \qquad (4.4\text{-}7)$$

where P = power in watts

P' = bin number.

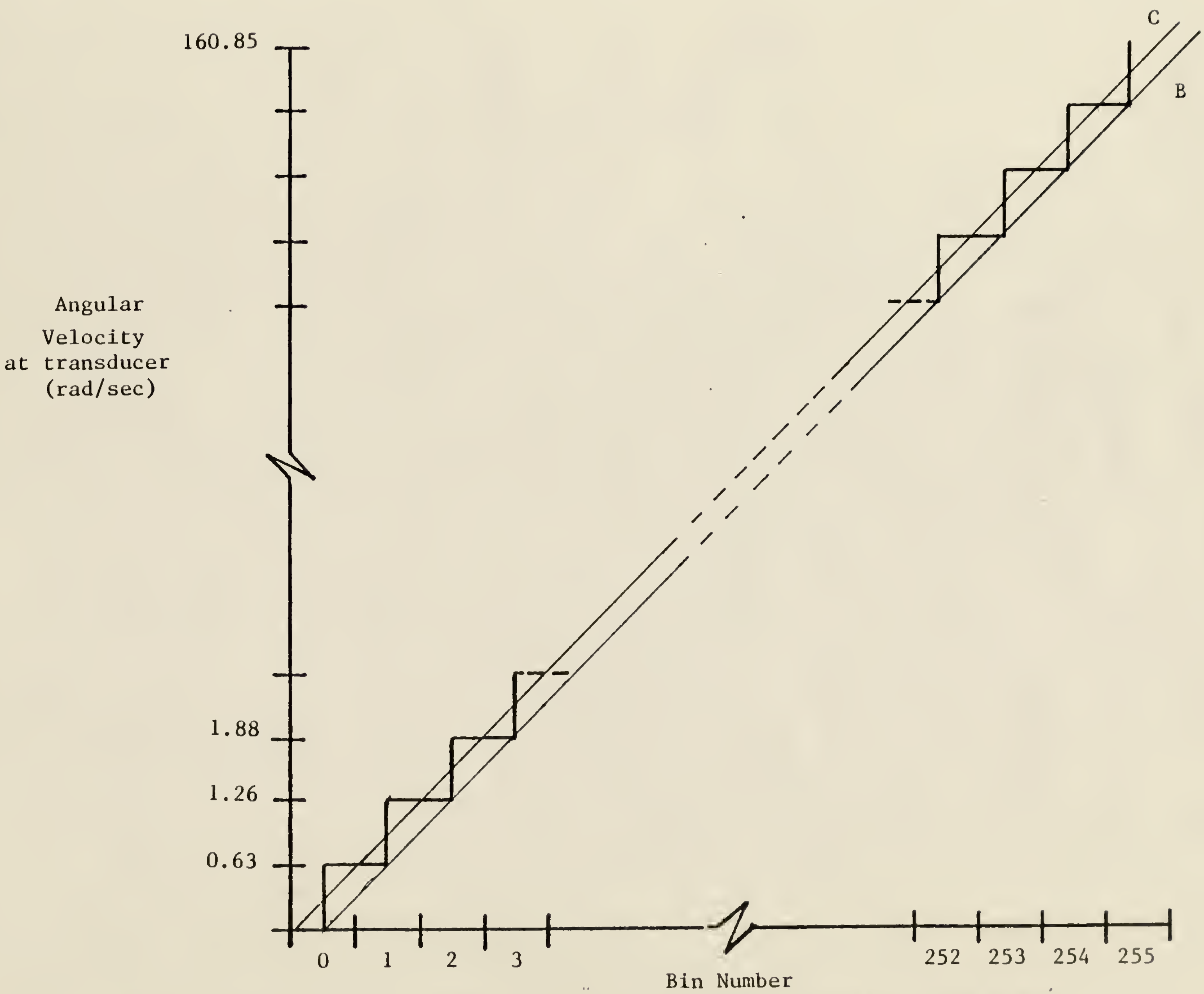


Fig. 4.4-2. Angular Velocity at Transducer Versus Bin Number.

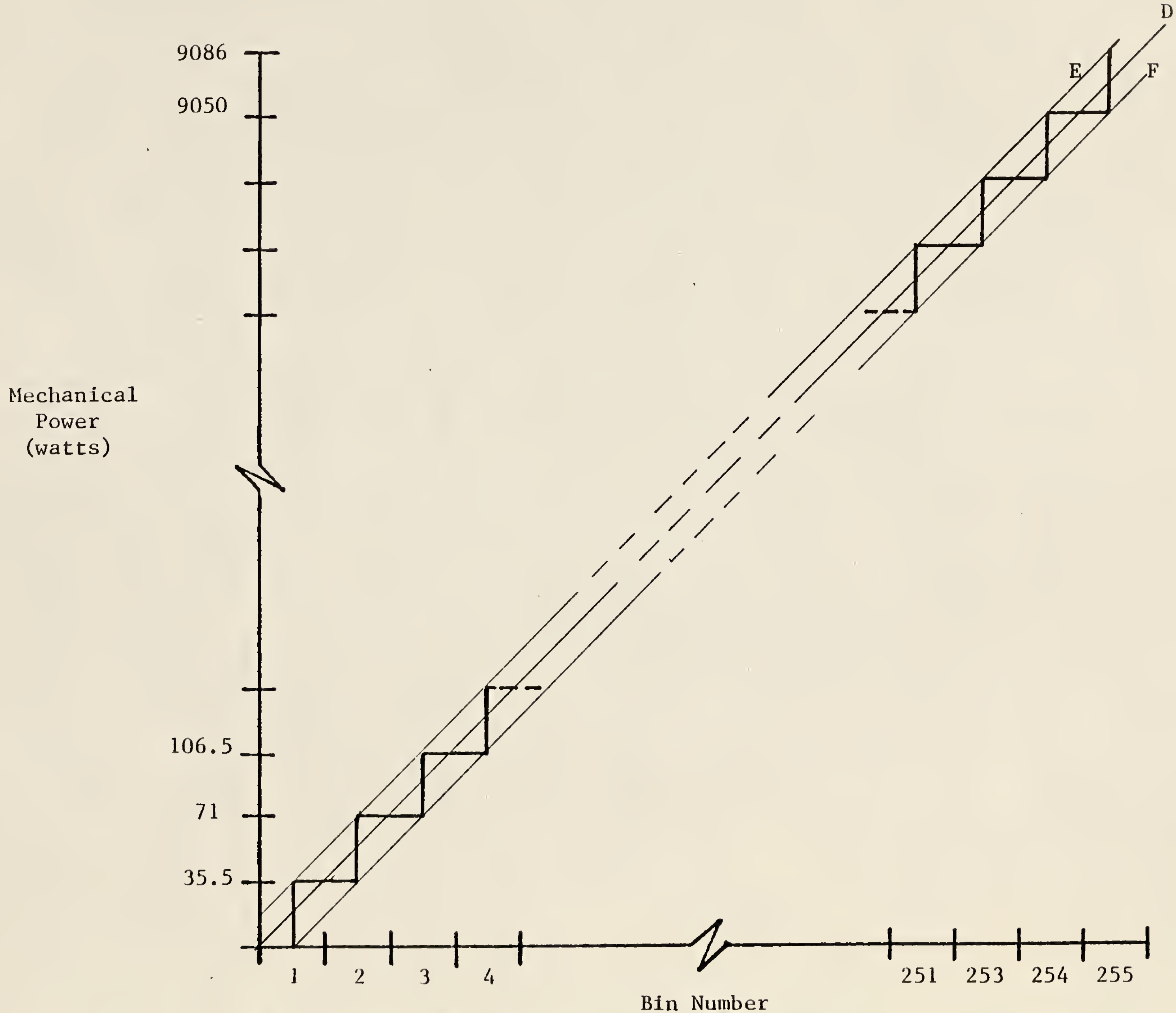


Fig. 4.4-3. Mechanical Power Versus Bin Number.

For example, assume that the sampled torque (T') equals 20 and the sampled angular velocity (ω') equals 10. The T',ω' multiplication would yield 200 or 60 W, which is a low estimate of power. Therefore, by using the product of the T' + 1, ω' + 1 multiplication averaged with the T', ω' product, a better estimate of the power will result, which is 215 or 77.5 W.

5. CONCLUSIONS

The KSU Wind Laboratory data acquisition system performed well and at the time of this writing is in use at the KSU Wind Laboratory. The system, although not elegant, is simple, low cost, and has enabled us to collect quality data.

There is only one major recommendation to be considered for the system. That is improved software. Better software would entail a more concisely written version and software that would run in ROM, for instant-on capabilities. The present software performs well, but alterations could be made to improve table functions. The tables could be moved to page zero and handled with zero page addressing, thus reducing software.

6. ACKNOWLEDGEMENTS

This work is dedicated to the author's father and mother, James M. and Geneva P. Babb.

The author thanks his major professor, Dr. G. L. Johnson, for expert advice during the course of this research, and Dr. M. S. P. Lucas for his assistance. Thanks are also given to the Department of Electrical Engineering at Kansas State University for financial assistance received while enrolled as a graduate student. Finally, the author expresses his appreciation for the understanding and the love given by his wife, Kathryn.

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8. APPENDICES

APPENDIX A

Modification of the S.D.S. 4k RAM Board [20] and Test Program [21]

The S.D.S 4k RAM board is assembled according to instructions given by S.D. Sales. The following modifications are made to adapt the RAM board for KIM-1 use.

1. Remove IC's 33, 35, 36 and 37. File these IC's for other projects.
2. Temporarily remove IC 39.
3. Jumper IC 39 socket pin 8 to 9 with a very short wire.
4. Bend pins 1, 8, 9, and 10 of IC 39 so that they point opposite from their original position.
5. Replace IC 39.
6. Using a piece of insulated wire about 2.5 inches long, strip about 1 inch of insulation from one end. From the component side of the board, push the stripped end all the way through address selection hole "a" which is near pin 1 of IC 34. Now, turn the board over, bend the wire flat, and push the end back through the other address selection hole "a" near pin 14 of IC 37. Solder both holes and clip the uninsulated excess.

   Strip the free end of the wire and push it into pin 3 of IC 33 socket.
7. Repeat step 6 three more times, connecting:

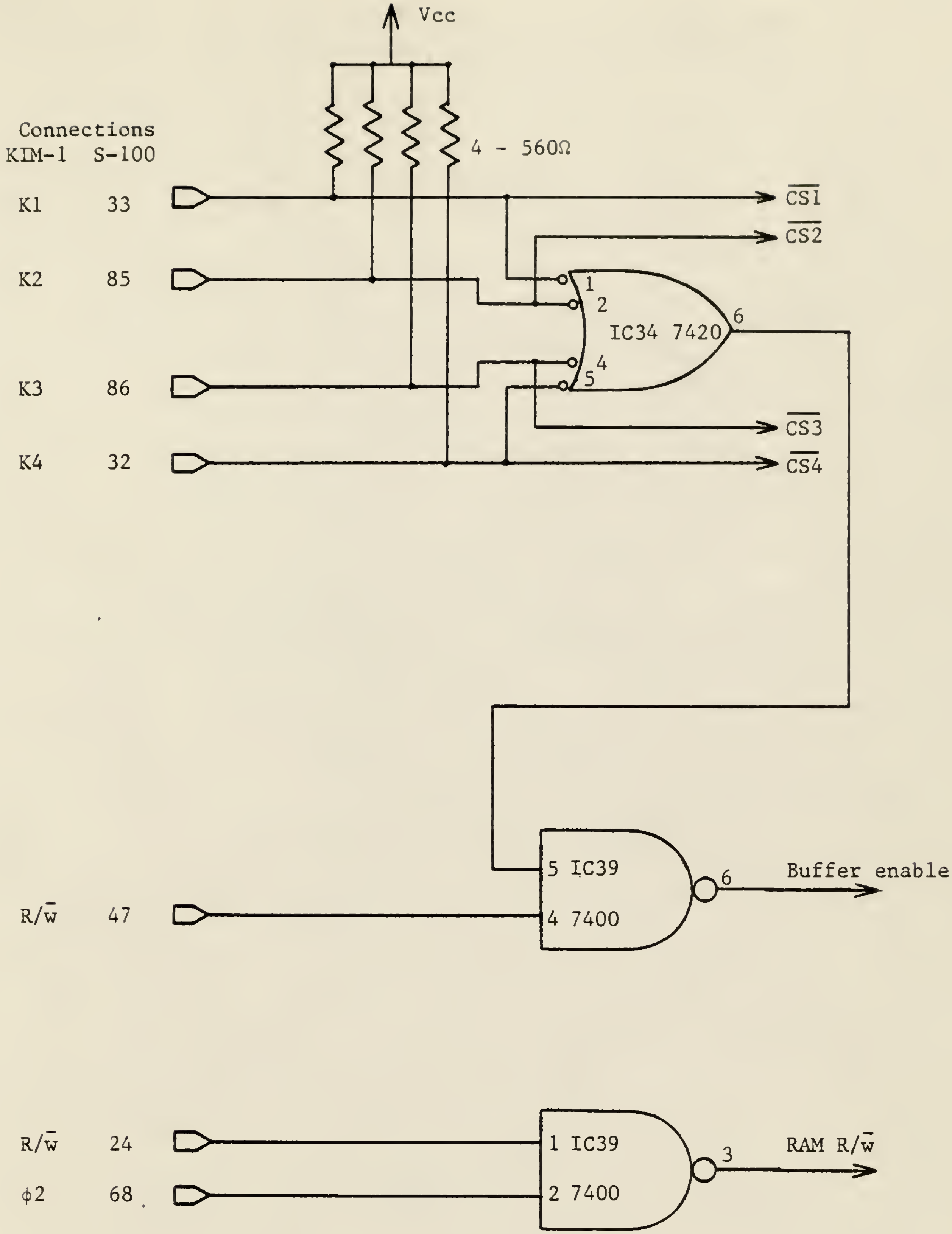
   b to b to pin 8 on IC 33 socket

   c to c to pin 11 on IC 33 socket

   d to d to pin 6 on IC 33 socket

8. Connect pin 1 of IC 39 (should be sticking straight up into the air) to a spare edge connector location such as 24.
9. Remove and address selection jumper wires which may be present in the holes between IC 34 and IC 37. Wire all four address selection holes $\bar{a}$, $\bar{b}$, $\bar{c}$, and $\bar{d}$ together on the component side of the board and connect to Vcc by inserting the end of the wire into pin 14 of IC 37. Make sure only $\bar{a}$, $\bar{b}$, $\bar{c}$, and $\bar{d}$ are so connected and solder these connections.
10. Bend the leads of four 560Ω 1/4 watt resistors into hairpins and cut the leads to about 1/4 of an inch past the end of the resistor. Then be sure the resistor leads are clear and free of all tarnish.
11. Insert one hairpin resistor into pins 13 and 12 on IC 37 socket and repeat for pin sockets 11 - 10, 9 - 8, and 5 - 6.
12. Finished.

The above procedure will modify the S.D. Sales logic to accommodate the KIM-1 decoding. The final modification diagram is given in the following pages. Also given is a table for the connection of the 4k RAM card to the KIM-1. A memory march test is provided to enable testing of the modified RAM.



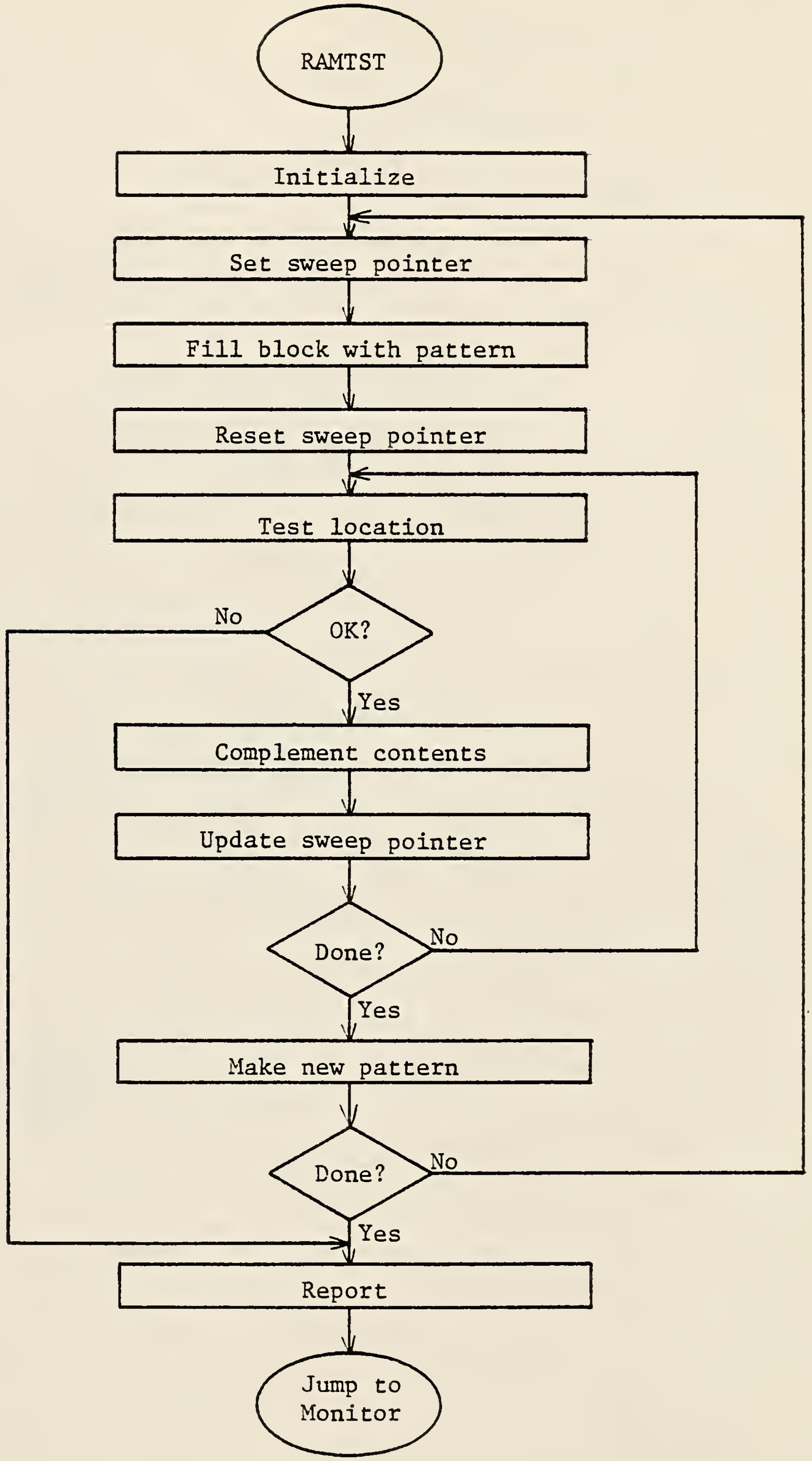
Logic diagram of final modifications.

Edge Connector for Modified S.D.S. 4k RAM

Locations

1	+8V	26		51	+8V	76	
2		27		52		77	
3		28		53		78	
4		29	A5	54		79	AØ
5		30	A4	55		80	A1
6		31	A3	56		81	A2
7		32	K4	57		82	A6
8		33	K1	58		83	A7
9		34	A9	59		84	A8
10		35	DO1	60		85	K2
11		36	DOØ	61		86	K3
12		37		62		87	
13		38	DO4	63		88	DO2
14		39	DO5	64		89	DO3
15		40	DO6	65		90	DO7
16		41	DI2	66		91	DI4
17		42	DI3	67		92	DI5
18		43	DI7	68	$\phi 2$	93	DI6
19		44		69		94	DI1
20		45		70		95	DIØ
21		46		71		96	
22		47	$R/\bar{w}$	72		97	
23		48		73		98	
24	$\overline{R/\bar{w}}$	49		74		99	
25		50	ground	75		100	ground

This program tests any RAM memory block below page 17 not including Ø1FAH to Ø1FFH (reserved for the stack). To test any memory block, place the lower memory block address into location 17F5H (low byte) and 17F6H (high byte) and the high memory block address plus 1 into location 17F7H (low byte) and 17F8H (high byte). Start the program at location 178ØH. If the memory test passes, the display will show the last address tested plus 1. If there is a bad location, the display will show that location. To test the memory with complemented test pattern, change MEMTST: to LDX #$FE and FLIP: to BCS NEXT.



Routine to test RAM.

Memory Test Program

Address	Code	Label	Mnemonic	Operand	Comments
178Ø	A2 01	MEMTST:	LDX	#$01	Install test pattern
1782	A9 8E	NEXT:	LDA	#$8E	Install volatile execution block
1784	8D EC 17		STA	VEB	(VEB) for STX
1787	2Ø 32 19		JSR	INTVEB	Set up starting address
178A	8A		%XA		Complement test pattern
178B	49 FF		EOR	#$FF	
178D	A8		TAY		and save in Y
178E	2Ø BE 17	FILL:	JSR	EXVEB	Execute VEB, test for done
1791	9Ø FB		BCC	FILL	If not done go back
1793	2Ø 32 19		JSR	INTVEB	Install starting address
1796	A9 EC	TEST:	LDA	#$EC	Install CPX in VEB
1798	8D EC 17		STA	VEB	
179B	2Ø EC 17		JSR	VEB	Test memory location
179E	DØ ØF		BNE	FAULT	If error install address
17AD	A9 8C		LDA	#$8C	Install STY in VEB
17A2	8D EC 17		STA	VEB	
17A5	2Ø BE 17		JSR	EXVEB	Execute VEB, test for done
17A8	9Ø EC		BCC	TEST	If not done go back
17AA	8A		TXA		Generate new test pattern
17AB	8A		ASL		
17AC	AA		TAX		
17AD	9Ø D3	FLIP1:	BCC	NEXT	If not done go back
17AF	86 F5	FAULT:	STX Z	#F5	Save test pattern
17B1	AD EE 17		LDA	VEB+2	Set up address of last cell
17B4	85 FB		STA A	$FB	Tested in display
17B6	AD ED 17		LDA	VEB+1	or ending address
17B9	85 FA		STA	Z$FA	
17BB	4C 22 1C		JMP	RST	Return to monitor
17BE	2Ø EC 17	EXVEB:	JSR	VEB	Execute VEB
17C1	2Ø EA 19		JSR	INCVEB	Increment address in VEB
17C4	AD ED 17		LDA	VEB+1	Test to see if ending
17C7	CD F7 17		CMP	EAL	address same as in
17CA	AD EE 17		LDA	VEB+2	VEB
17CD	ED F8 17		SBC	EAH	
17DØ	6Ø		RTS		

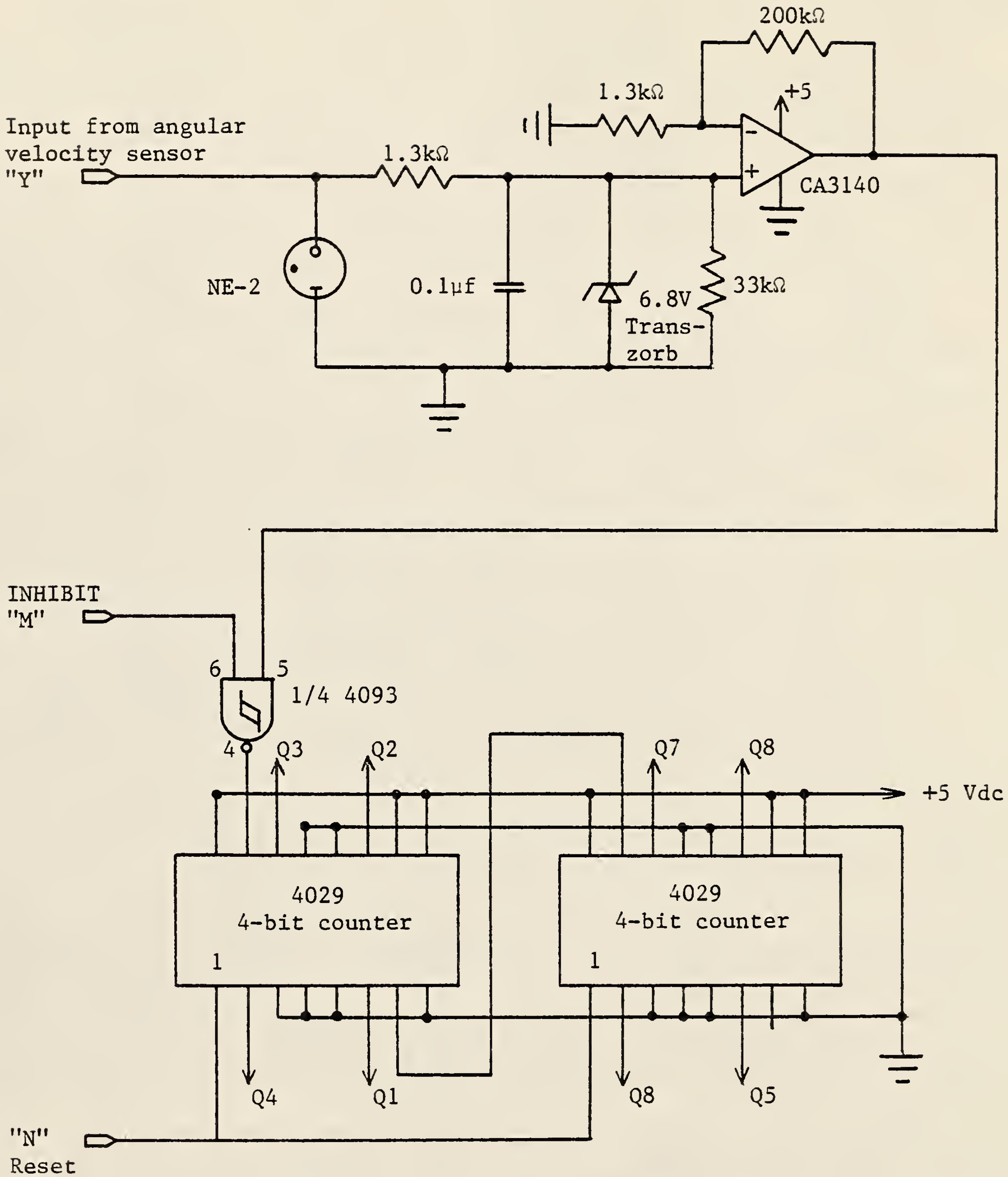
APPENDIX B

Multiplexer-Counter Board

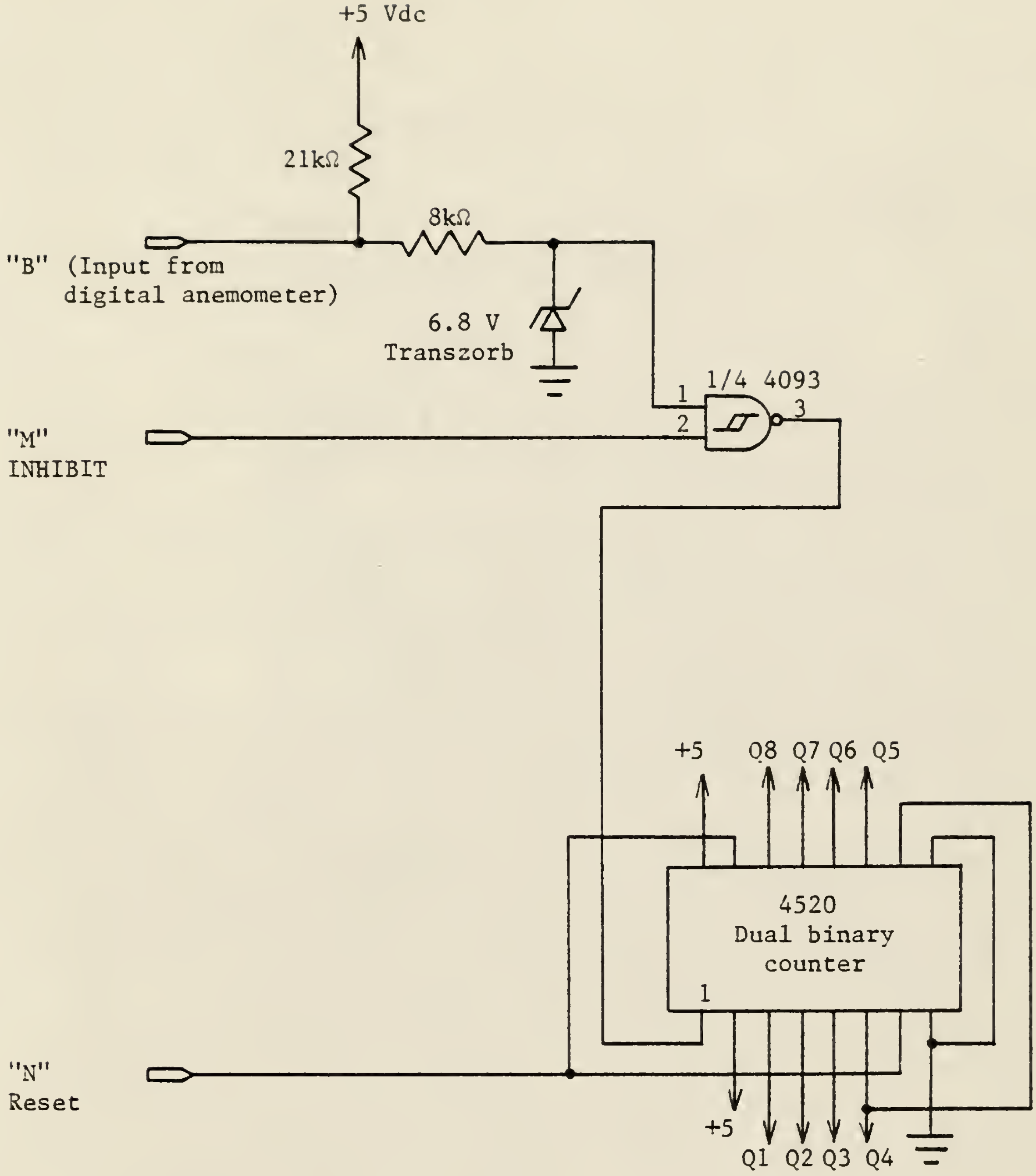
The schematic and edge connector locations for the Multiplexer-Counter Board are given on the following pages.

Mux-Counter Board Edge Connector

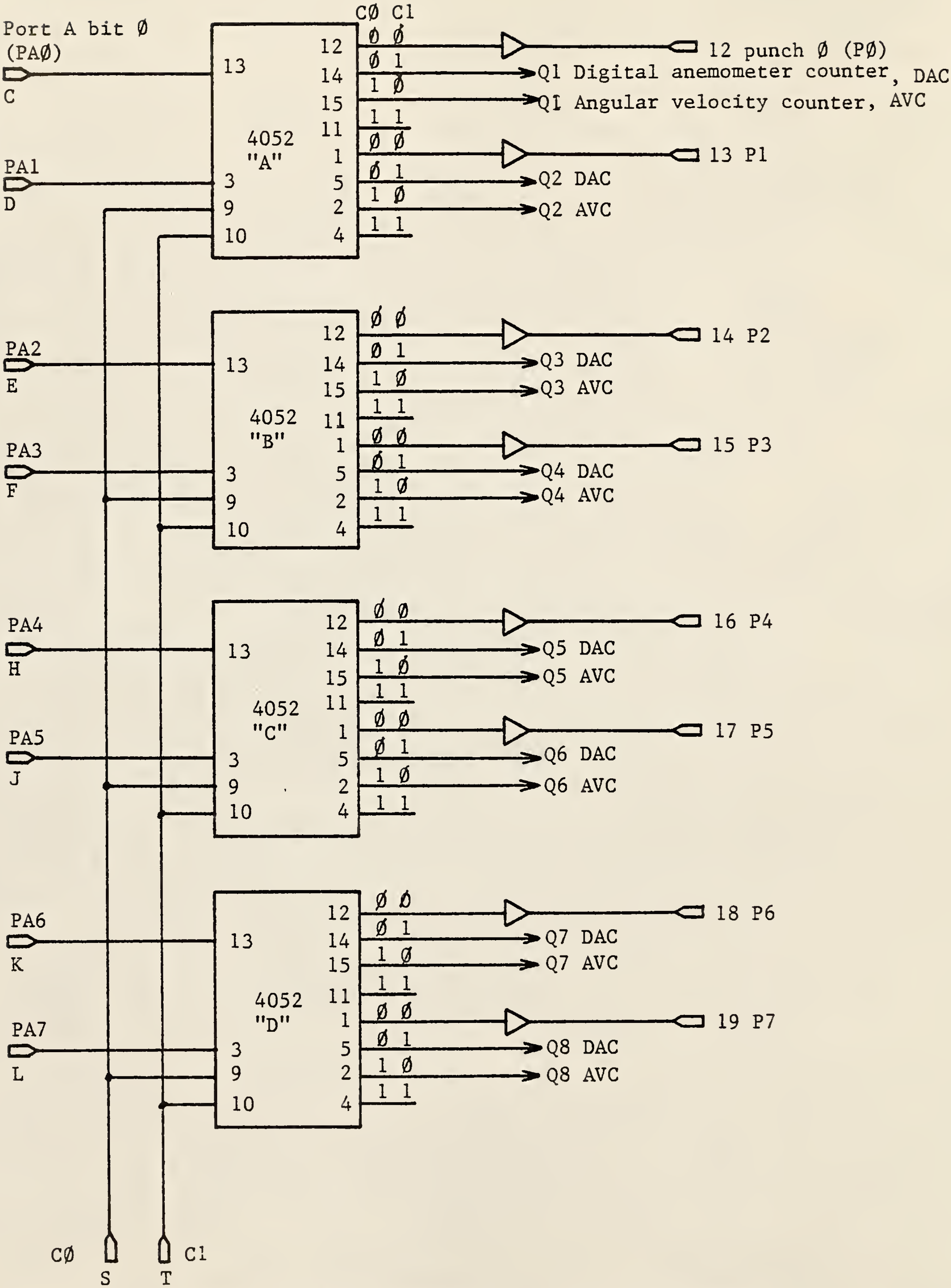
PIN NO.			PIN NO.			
1	+5 Vdc		A	+5 Vdc		
2	NC		B	Digital Anemometer input		
3	NC		C	Port AØ		
4	NC		D		A1	
5	NC		E		A2	
6	NC		F		A3	
7	NC		H		A4	
8	NC		J		A5	
9	NC		K		A6	
10	NC		L		A7	
11	Punch		M		B0	Inhibit counters
12	Data 1		N		B1	Reset counters
13	Data 2	To	P		B2	Busy (punching)
14	Data 3	Paper	R		B3	Punch Command
15	Data 4	Tape	S		B4	CØ
16	Data 5	Punch	T		B5	C1
17	Data 6		U	Power to Paper Tape Punch		
18	Data 7		V	NC		
19	Data 8		W	NC		
20	NC		X	NC		
21	NC		Y	Angular Velocity Input		
22	GND		Z	GND		



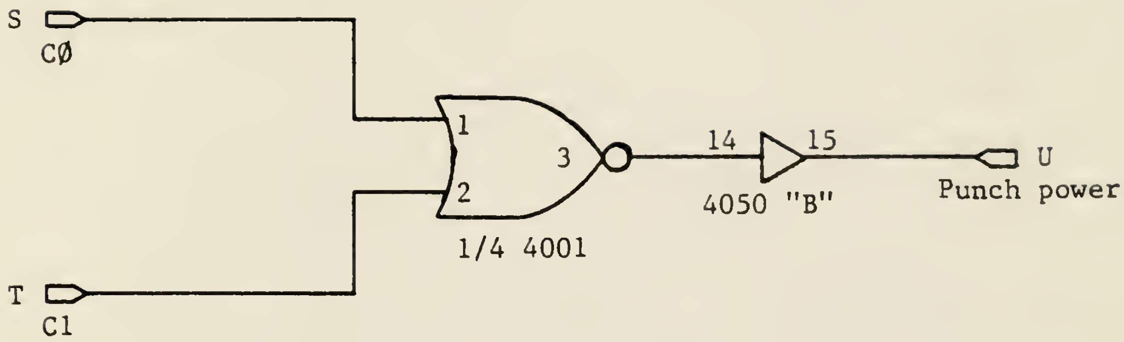
Angular velocity signal conditioning and pulse rate counter.



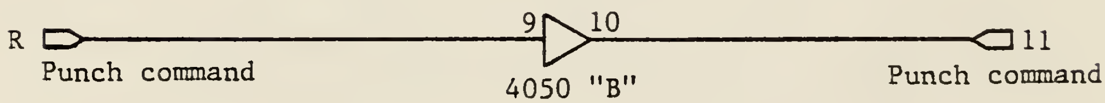
Digital anemometer input conditioning and pulse rate counter. Components are located on the Multiplexer - Counter board.



Multiplexer and punch buffers. Numbers and letters are edge card connector orientations.



Punch power configuration.



Buffer for punch command.

KIM-1 Application Connector

Pin No.		Pin No.	
1	GND	A	+ 5 Vdc
2	A3	B	
3	A2	C	
4	A1	D	
5	A4	E	
6	A5	F	
7	A6	H	
8	A7	J	
9	BØ	K	Decode Enable (GND)
10	B1	L	Audio IN
11	B2	M	
12	B3	N	+ 12 Vdc
13	B4	P	Audio Out (HI)
14	AØ	R	TTY KYBD RTRN(+)
15	B7*	S	TTY PTR RTRN(+)
16	B5	T	TTY KYBD
17		U	TTY PTR
18		V	
19		W	
20		X	
21		Y	
22	closed for TTY	Z	
	open for keyboard		

*IRQ from expansion connection Pin 4 is connected through a switch to B7.

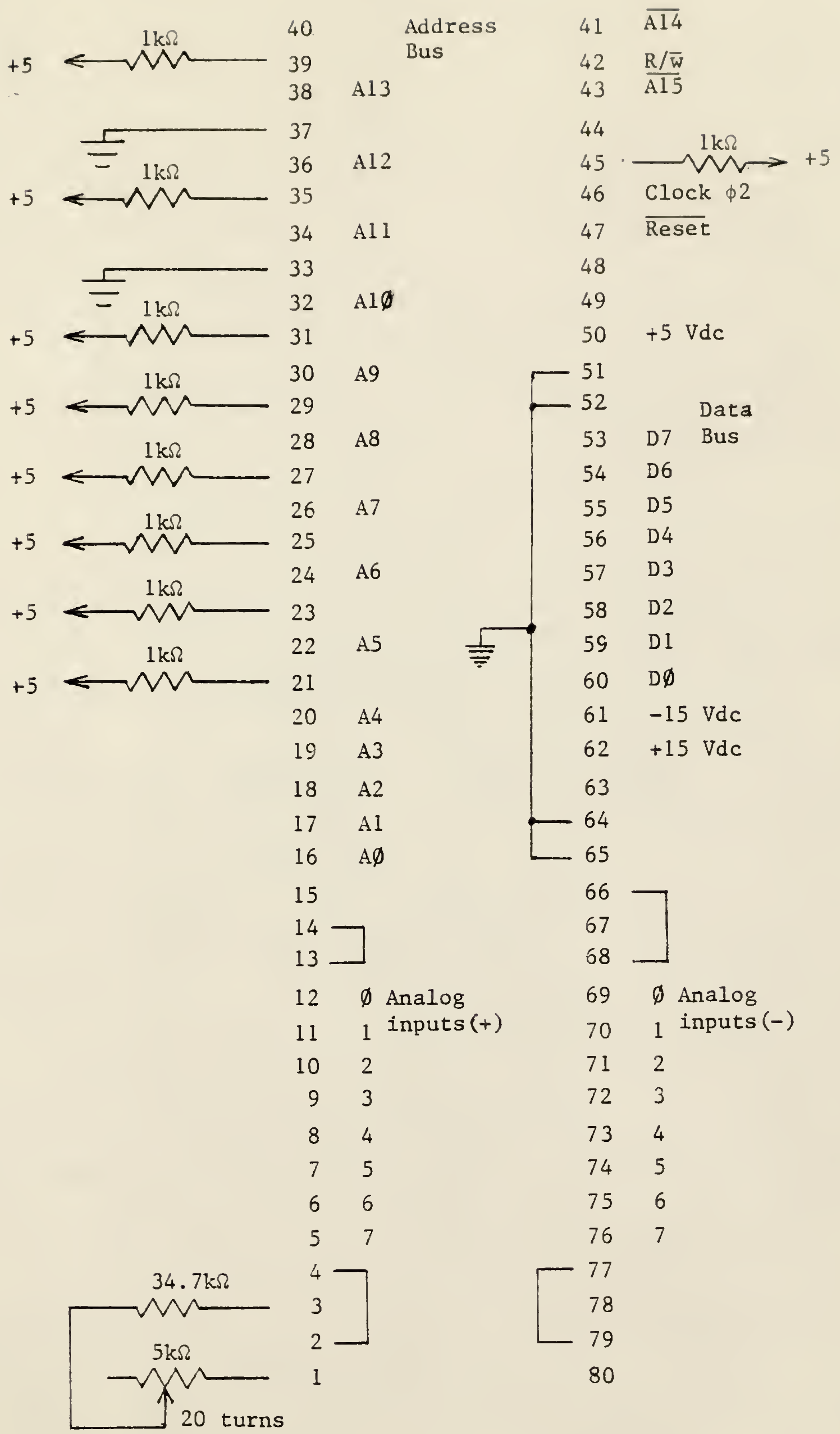
APPENDIX C

MP21 Connections

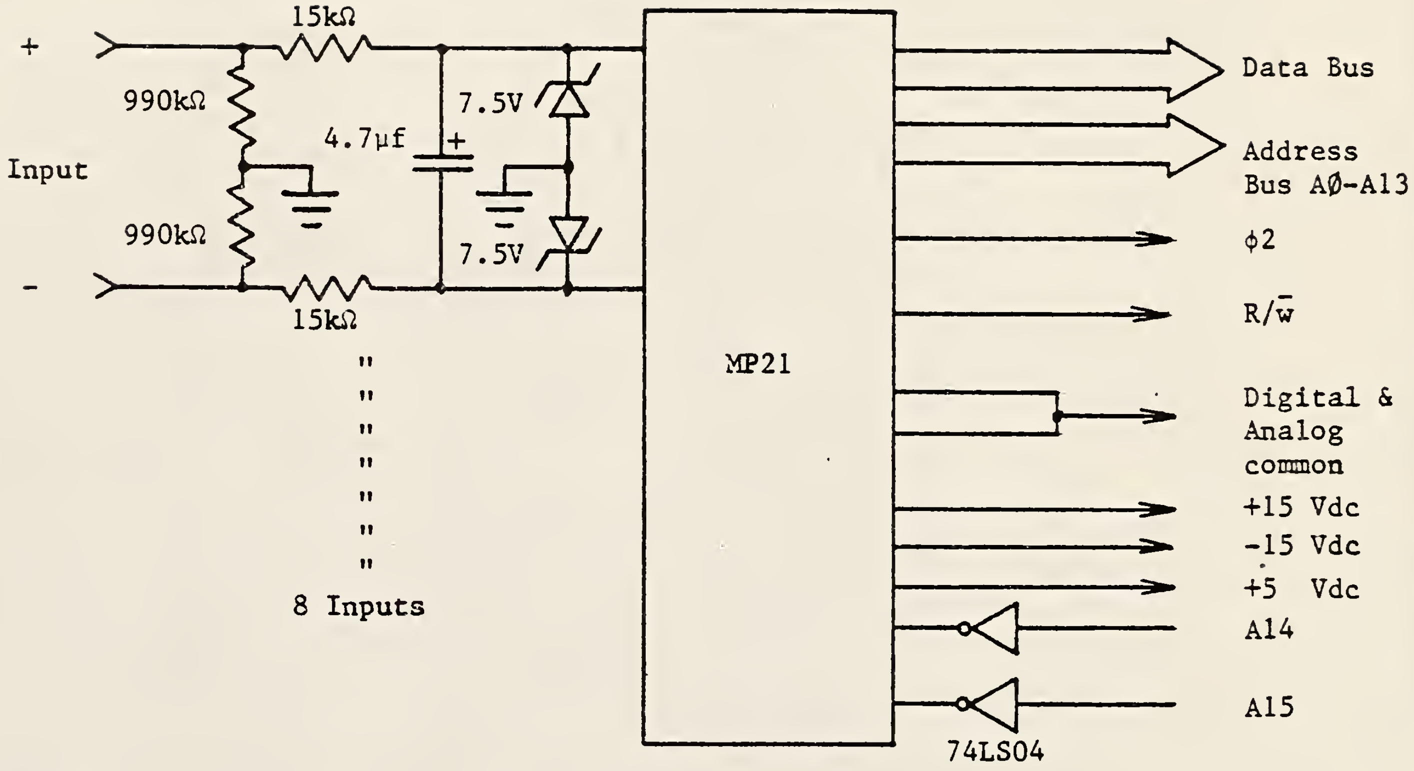
This appendix gives block diagrams, pin connections, and edge card connections for the A/D board.

Edge Connection for A/D Board

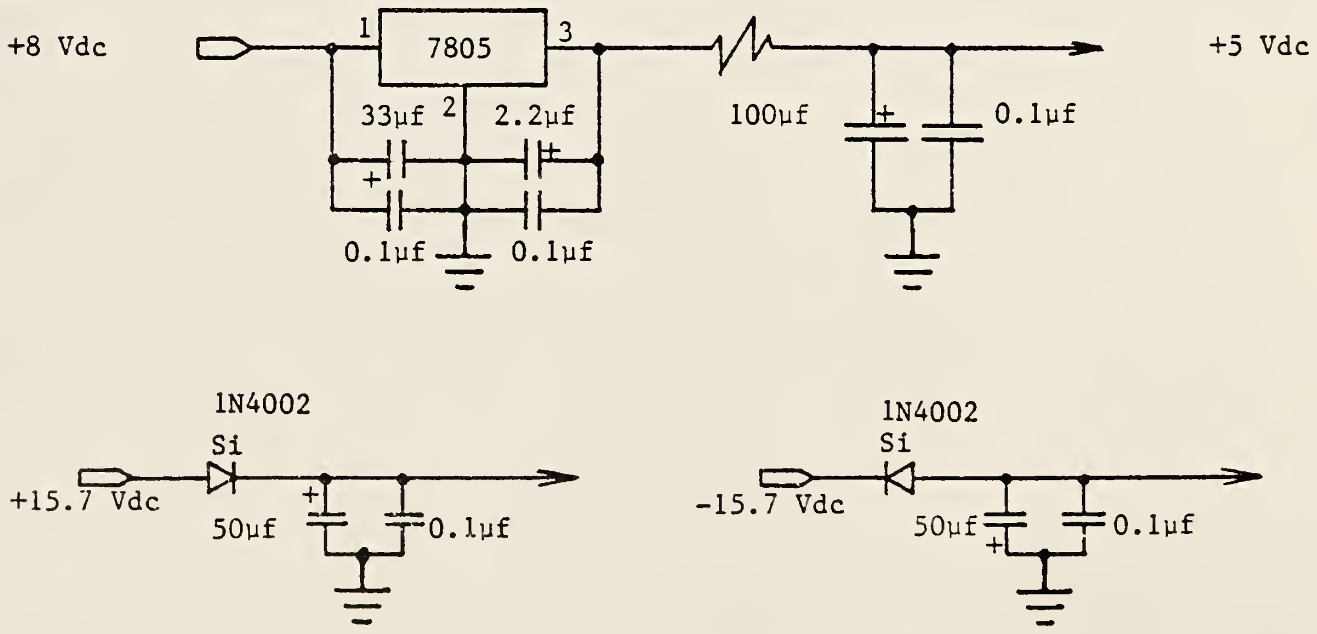
No.			No.			No.			No.		
1	+8 Vdc		26			51	+8 Vdc		76		
2	+15.7 Vdc		27			52	-15.7 Vdc		77		
3			28			53			78		
4			29	Address Bus:	A5	54			79	Address Bus:	AØ
5			30		A4	55			80		A1
6			31		A3	56			81		A2
7			32		A15	57			82		A6
8			33		A12	58	Analog Input:	+7	83		A7
9			34		A9	59		-7	84		A8
10			35			60		+6	85		A13
11			36			61		-6	86		A14
12	Analog Input:	+5	37		A1Ø	62		-5	87		A11
13		+4	38			63		-4	88		
14		+3	39			64		-3	89		
15		+2	40			65		-2	90		
16		+1	41	Data Bus:	D2	66		-1	91	Data Bus:	D4
17		+Ø	42		D3	67		-Ø	92		D5
18			43		D7	68	Clock $\phi 2$		93		D6
19			44			69			94		D1
20			45			70			95		DØ
21			46			71			96		
22			47	$R/\overline{w}$		72			97		
23			48			73			98		
24			49			74			99		
25			50	ground		75	$\overline{\text{Reset}}$		100	ground	



MP21 Connections



Block diagram of the Analog Microperipheral connection.



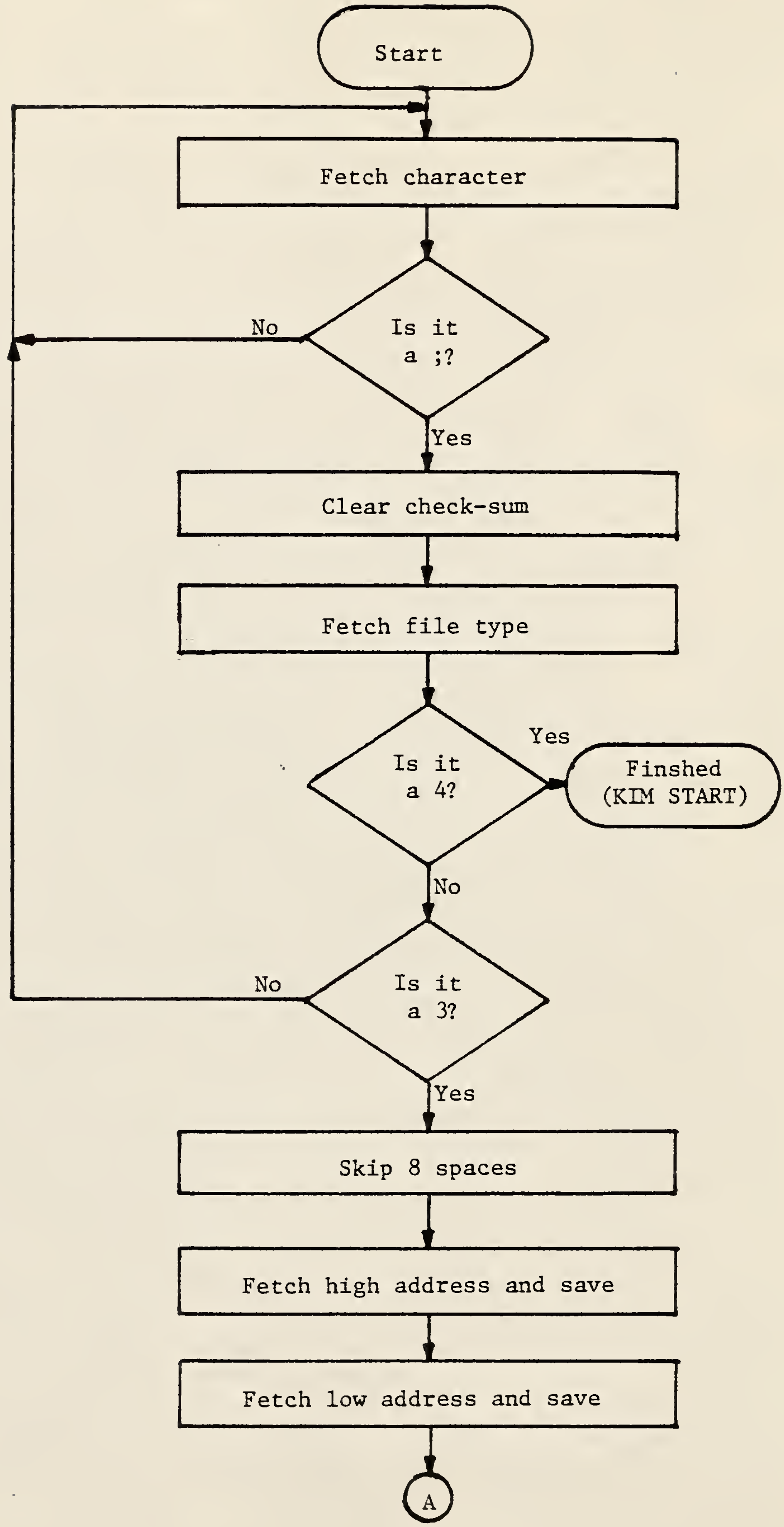
Power regulation and filtering on the Analog Microperipheral board.

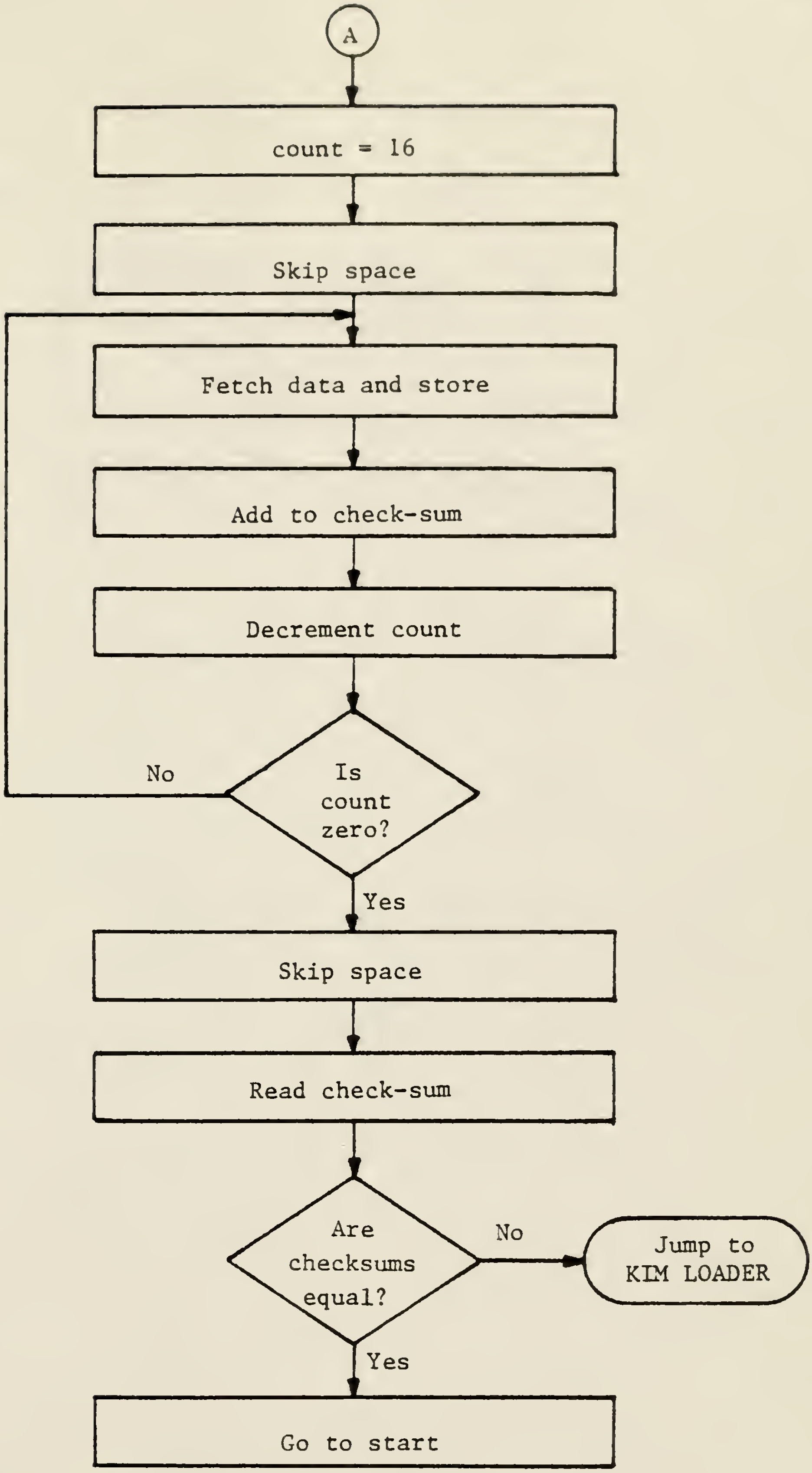
APPENDIX D

Cross-Assembler Reader

The program included in this section loads a paper tape coded program received from the MOS Technology cross-assembler into the KIM-1. To use the program, do the following:

1. Set address ØØF1H to ØØ.
2. Load cross-assembler reader program.
3. Set display pointer at 13ØØH.
4. Start the program (push GO).
5. Insert the cross-assembly tape into the tape reader.
6. Start the paper tape reader.
7. KIM-1 will return to the monitor when finished. If in error, the TTY will type 'ERR KIM'. Stop the tape reader and restart the tape before the error and restart the program at 13ØØH.


Start
Fetch character
Is it a ;?
No
Yes
Clear check-sum
Fetch file type
Is it a 4?
Yes
Finshed (KIM START)
No
Is it a 3?
No
Yes
Skip 8 spaces
Fetch high address and save
Fetch low address and save
A



Flow chart of program to load paper tape from cross-assembler.

Code for Cross-Assembler Reader

Location	OP Code		Mnemonic	Comments
13ØØ	2Ø	LOAD	JSR GETCH	Fetch character and
13Ø1	5A			look for ;.
13Ø2	1E			
13Ø3	C9		CMP #$3B	
13Ø4	3B			
13Ø5	DØ		BNE LOAD	
13Ø7	A9		LDA #$ØØ	IF; clear
13Ø8	ØØ			checksum.
13Ø9	85		STA CHKSUM	
13ØA	F7			
13ØB	85		STA CHKHI	
13ØC	F6			
13ØD	2Ø		JSR FETCH	Fetch character and
13ØE	5A			
13ØF	1E			if it is 4 return
131Ø	C9		CMP #'4'	to KIM-1 monitor.
1311	34			
1312	DØ		BNE COMP	
1313	Ø3			
1314	4C		JMP START	
1315	4F			
1316	1C			
1317	C9	COMP	CMP #'3'	If character is a
1318	33			3 skip 8
1319	DØ		BNE LOAD	spaces.
131A	E5			
131B	A2		LDX #8	
131C	Ø8			
131D	2Ø	LOOP1	JSR GETCH	Fetch and discard
131E	5A			for the 8 spaces.
131F	1E			
132Ø	CA		DEX	
1321	DØ		BNE LOOP1	If 8 spaces go on.
1322	FA			
1323	A2		LDX #$1Ø	Number of data
1324	1Ø			bytes per record.
1325	AØ		LDY #$ØØ	Clear Y.
1326	ØØ			
1327	2Ø		JSR GETBYT	Fetch high byte
1328	9D			address.
1329	1F			
132A	85		STA POINTH	Save.
132B	FB			
132C	2Ø		JSR GETBYT	Fetch low byte address.
132D	9D			
132E	1F			

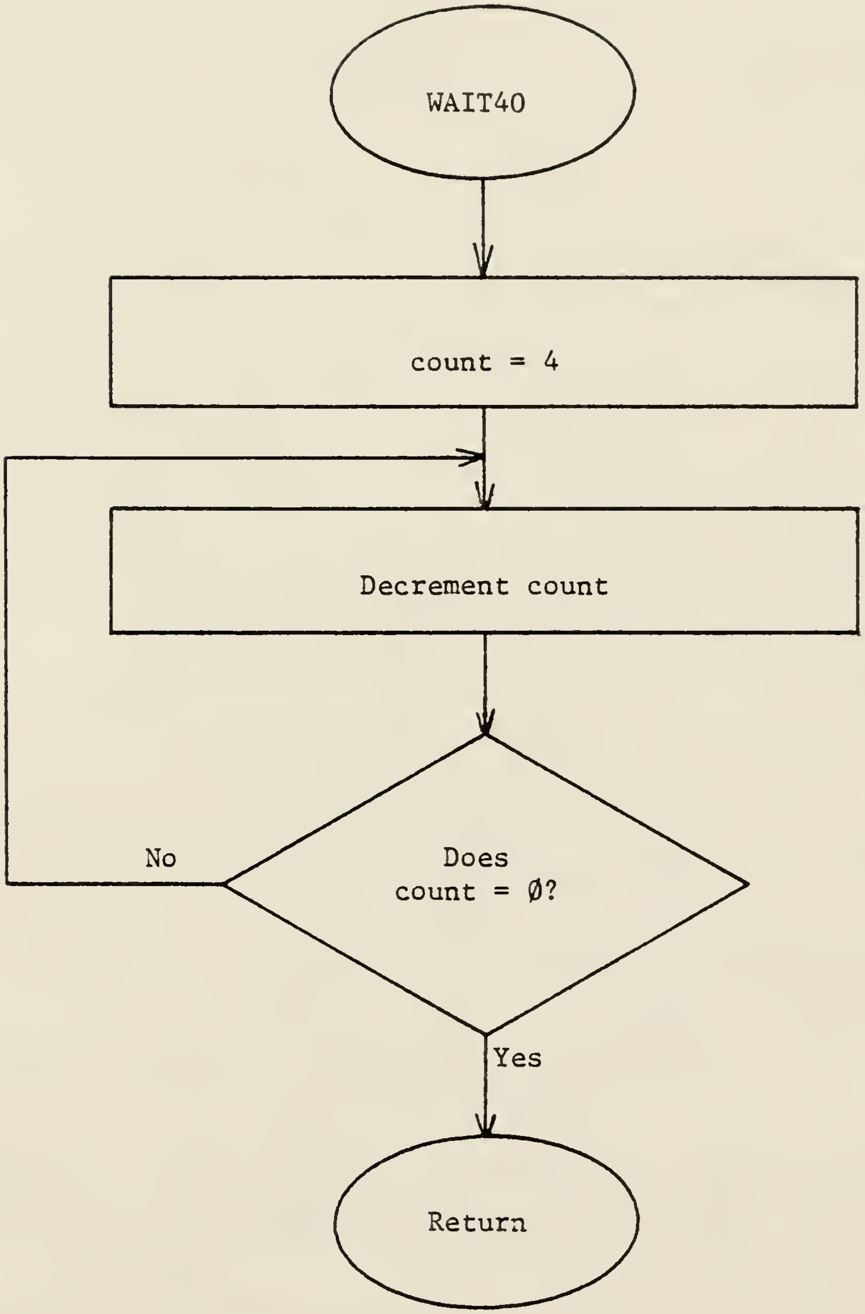
Location	OP Code		Mnemonic	Comments
132F	85		STA POINTL	Save.
133Ø	FA			
1331	2Ø		JSR FETCH	Skip space.
1332	5A			
1333	1E			
1334	2Ø	LOAD1	JSR GETBYT	Fetch data.
1335	9D			
1336	1F			
1337	91		STA (POINTL),Y	Store.
1338	FA			
1339	2Ø		JSR CHK	Add to checksum.
133A	91			
133B	1F			
133C	2Ø		JSR INCPT	Next address.
133D	63			
133E	1F			
133F	CA		DEX	Decrement number of data bytes per record.
134Ø	DØ		BNE LOAD1	Branch and fetch until
1341	F2			all data bytes are read.
1342	2Ø		JSR GETCH	Skip space.
1343	5A			
1344	1E			
1345	2Ø		JSR GETBYT	Fetch checksum
1346	9D			high byte.
1347	1F			
1348	C5		CMP CHKHI	Compare to KIM's
1349	F6			value.
134A	DØ		BNE ERROR	If not equal branch
134B	ØA			to ERROR.
134C	2Ø		JSR GETBYT	Fetch checksum
134D	9D			low byte.
134E	1F			
134F	C5		CMP CHKSUM	Compare to KIM's
135Ø	F7			value.
1351	DØ		BNE ERROR	If not equal branch
1352	Ø3			to ERROR.
1353	4C		JMP LOAD	Return to fetch
1354	ØØ			next record.
1355	13			
1356	4C	ERROR	JMP $1D3E	On error jump
1357	3E			to KIM error
1358	1D			loader routine.

APPENDIX E

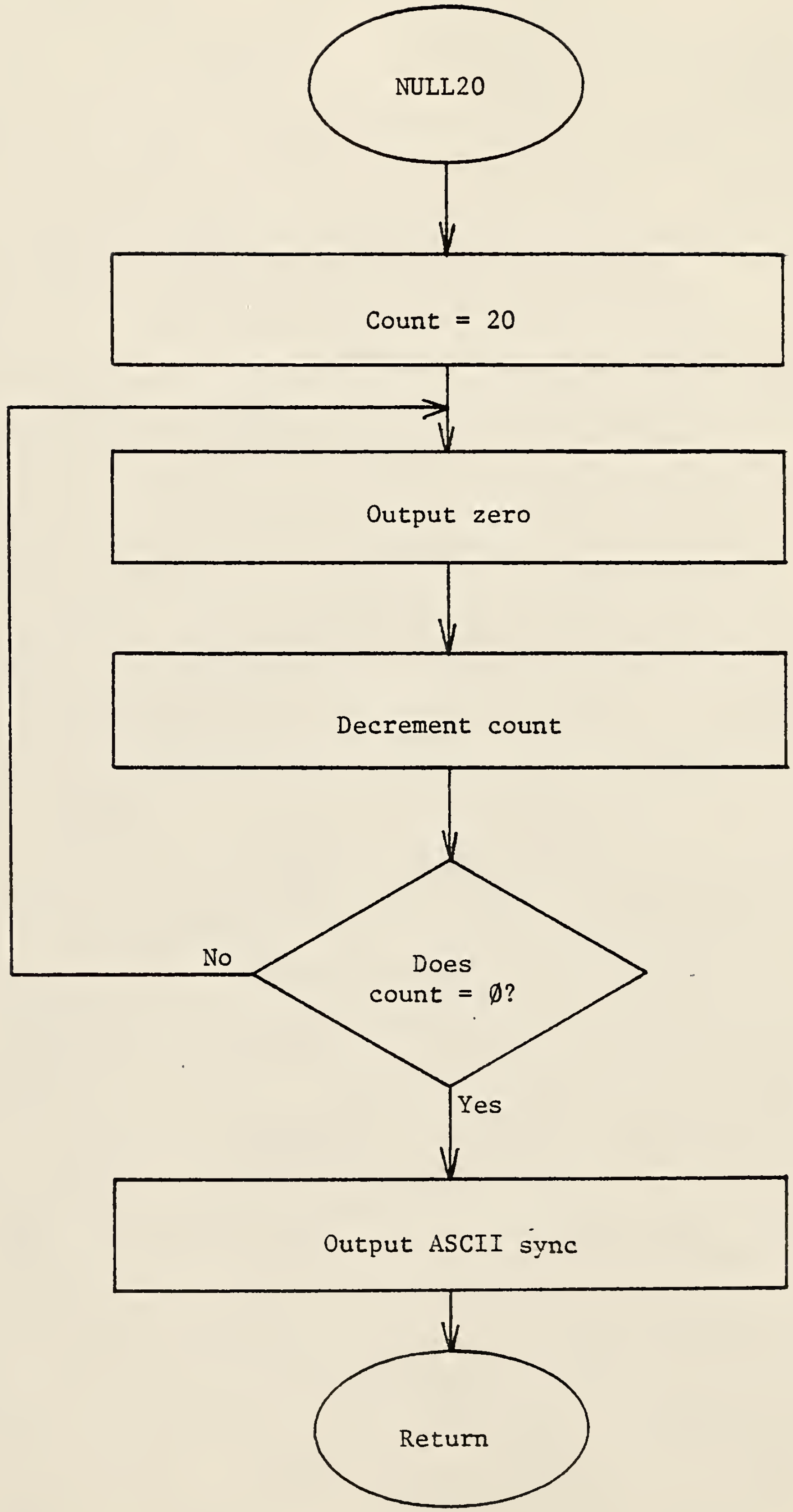
System Program Flow Charts

Flow charts of the complete system program and listings are given. The name of each flow chart corresponds to a routine in the listing.

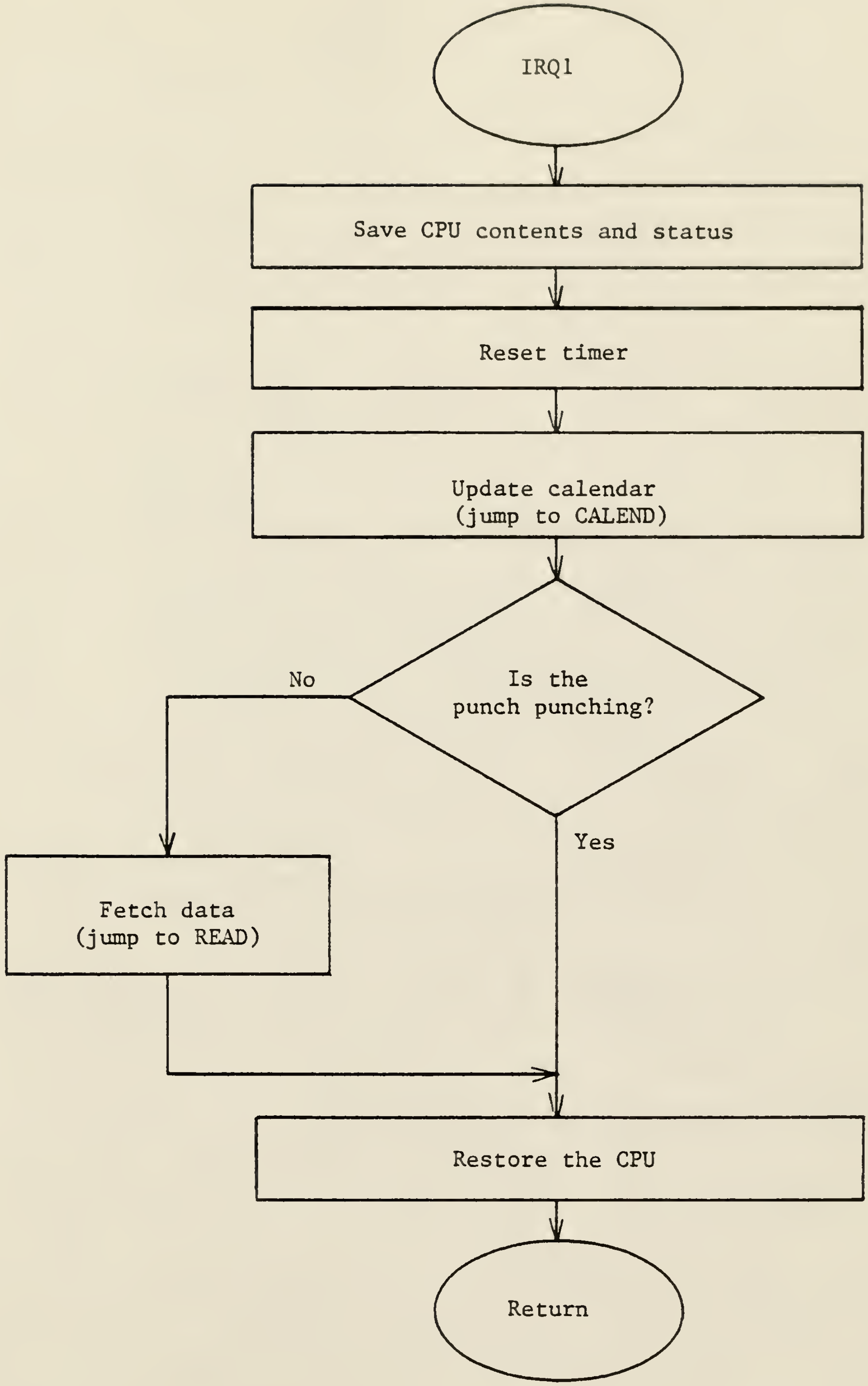
Routine Name	Function
WAIT4Ø	Time delay of 40 microseconds.
NULL2Ø	Output 20 nulls and an ASCII synch.
IRQ1	Interrupt routine for binned acquisition mode.
IRQ2	Interrupt routine for sequential acquisition mode.
MULT	8-bit by 8-bit multiply.
READ	Read digital transducers.
CALEND	Update calendar.
CLEARB	Clear bins.
OUTPOK	Output contents of the accumulator to the punch.
SCX-DIS	Select and display data.
OUTPUT	Turn on the paper tape punch.
DATACT	Collect data.
OUTSUB	Output contents of the bins.
CLEARØ	Initialize the processor.
ISOUTF	Idle until data collection.
AINA	Collect data (part of DATACT)
ONWAR	Turn off the punch.



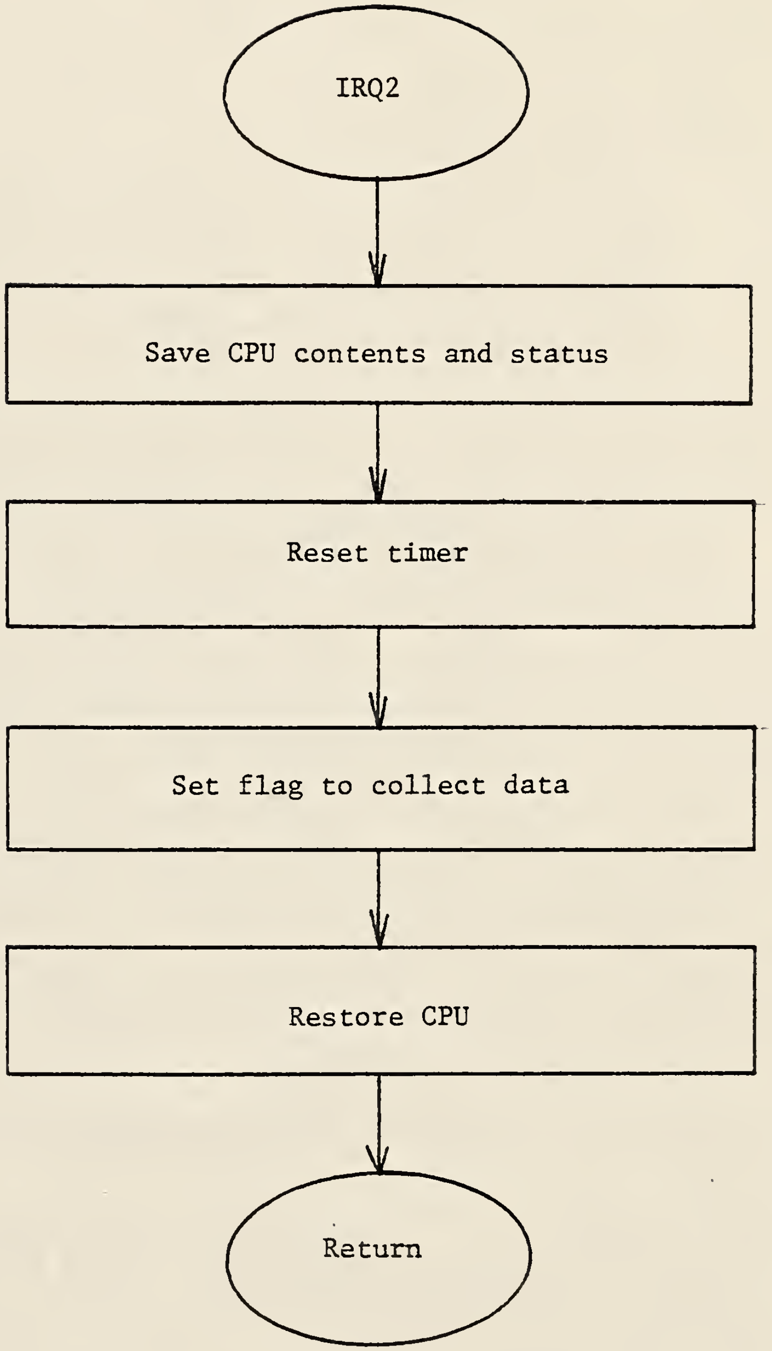
WAIT40 — Subroutine to wait 40 microseconds.



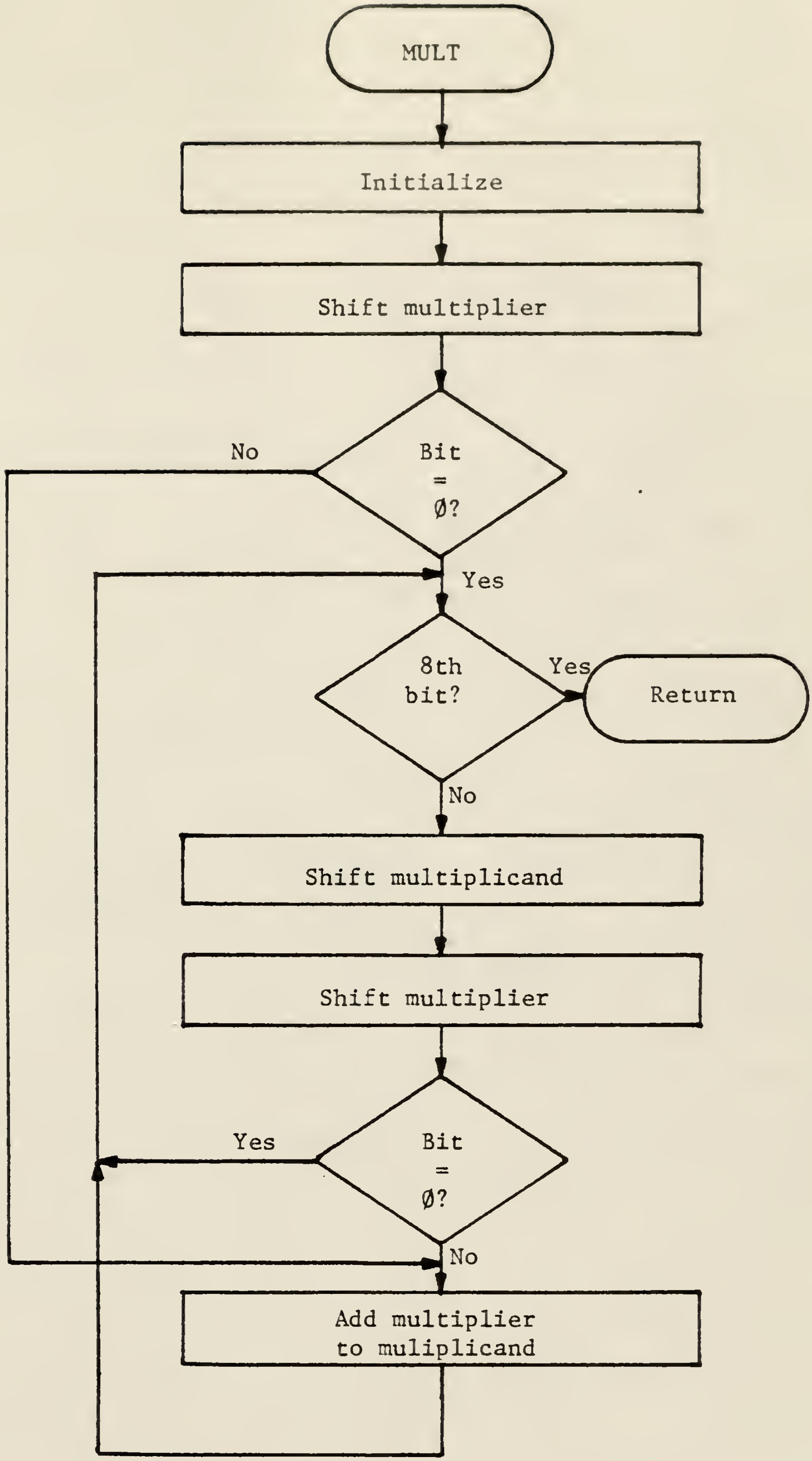
NULL20 — Subroutine to output 20 nulls and an ASCII sync.



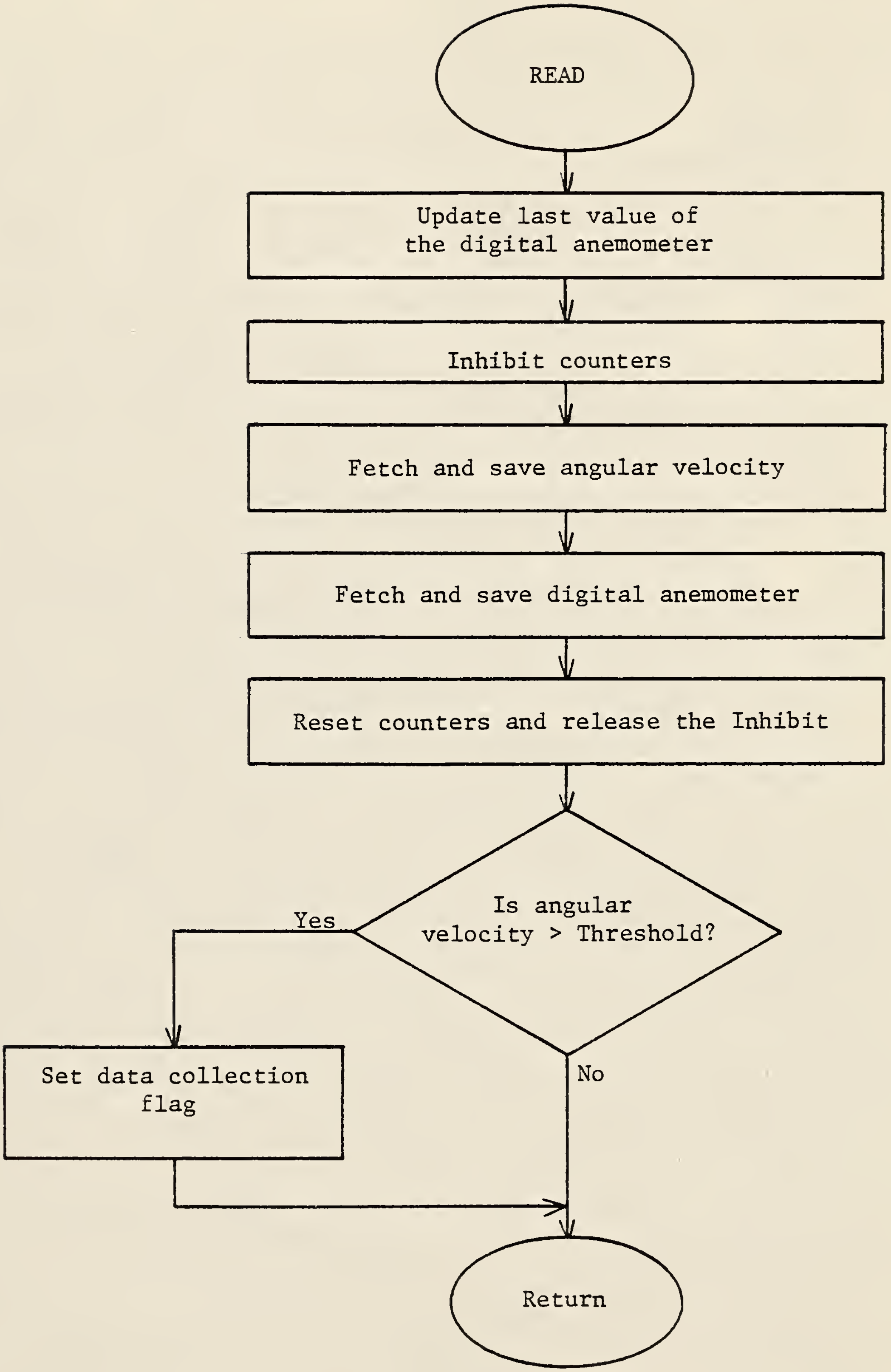
IRQ1 - Interrupt routine for binned data acquisition program.



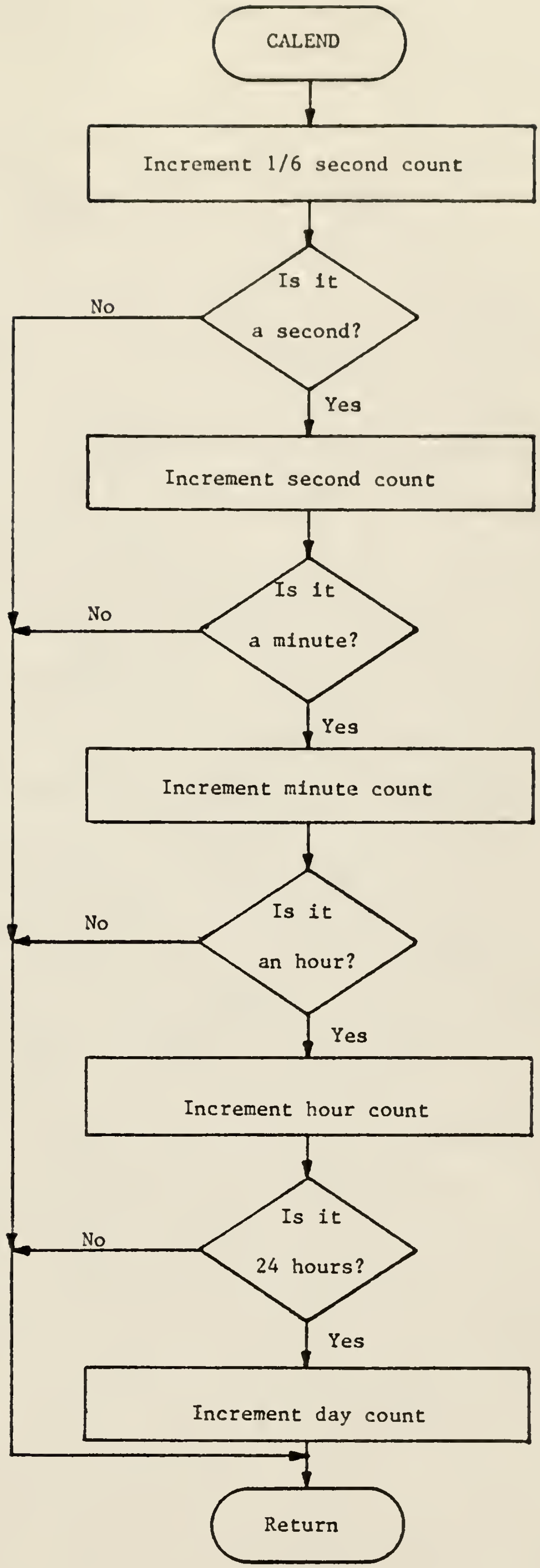
IRQ2 - Interrupt routine to set timer for sequential routine.



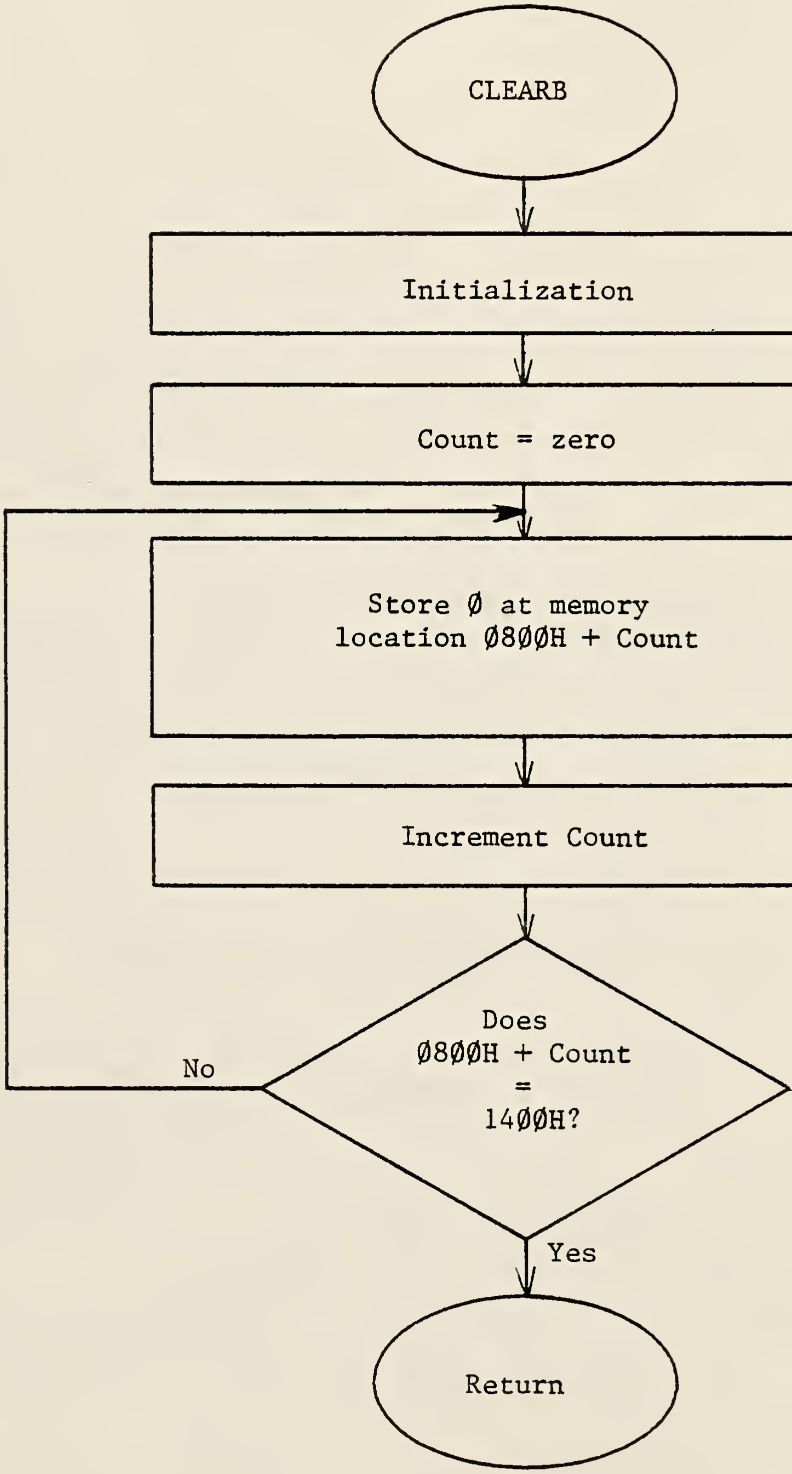
MULT — Multiply subroutine for two 8 bit unsigned numbers.



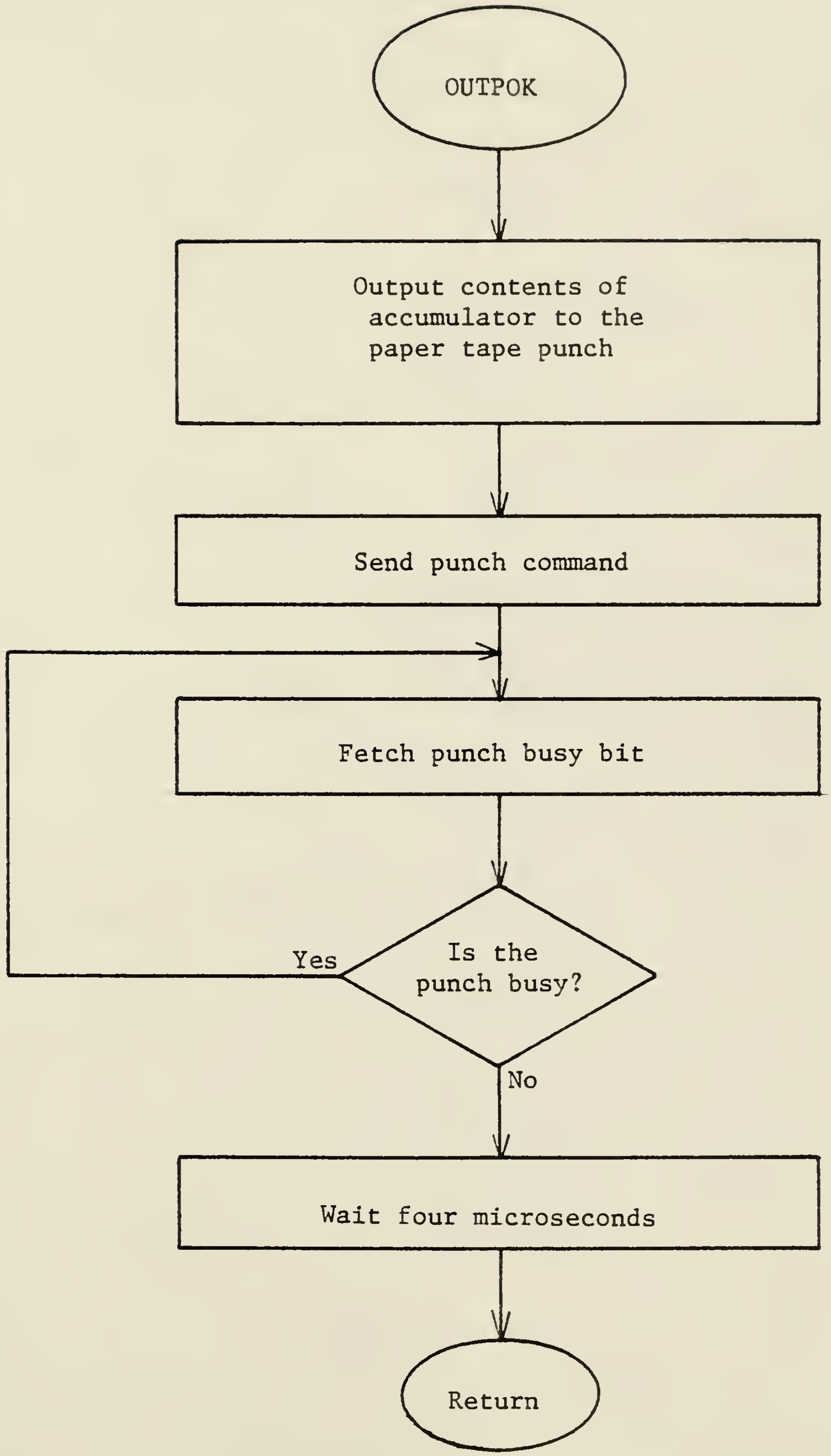
READ — Subroutine to fetch digital anemometer and angular velocity values. The routine has adjustable threshold for data collection.



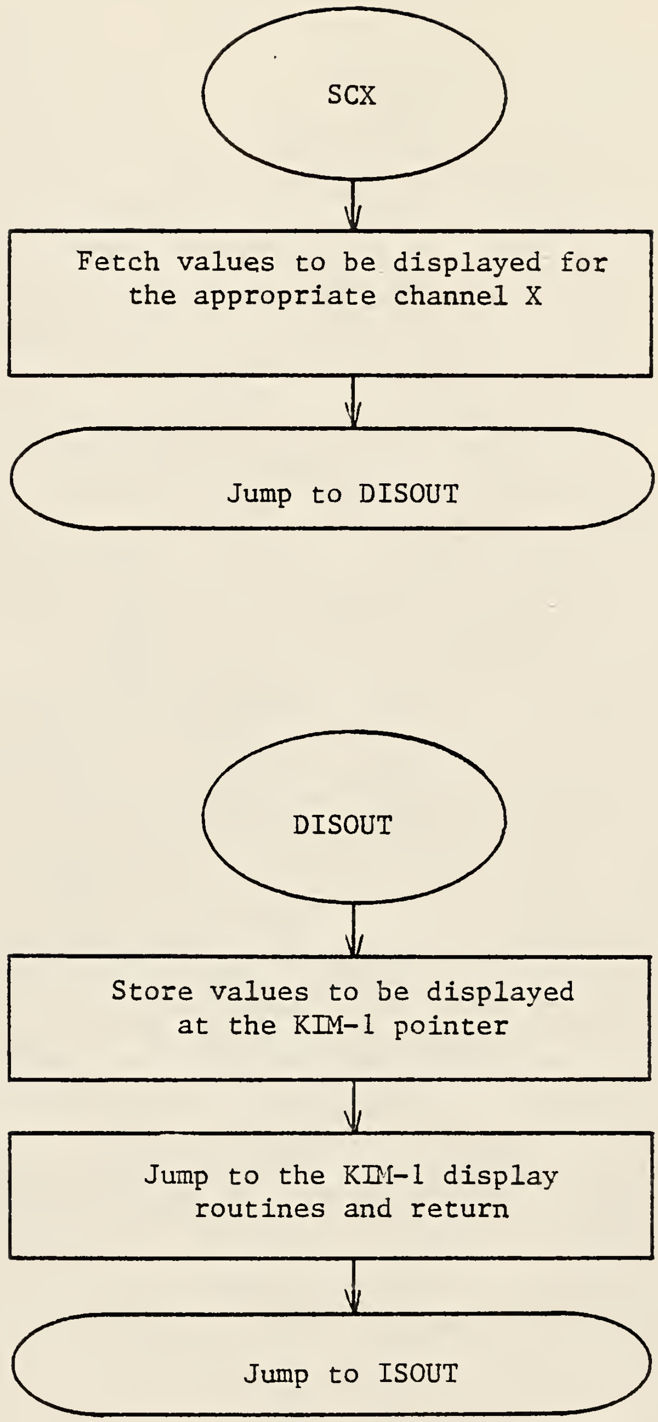
CALEND — Calendar subroutine (does not update year).



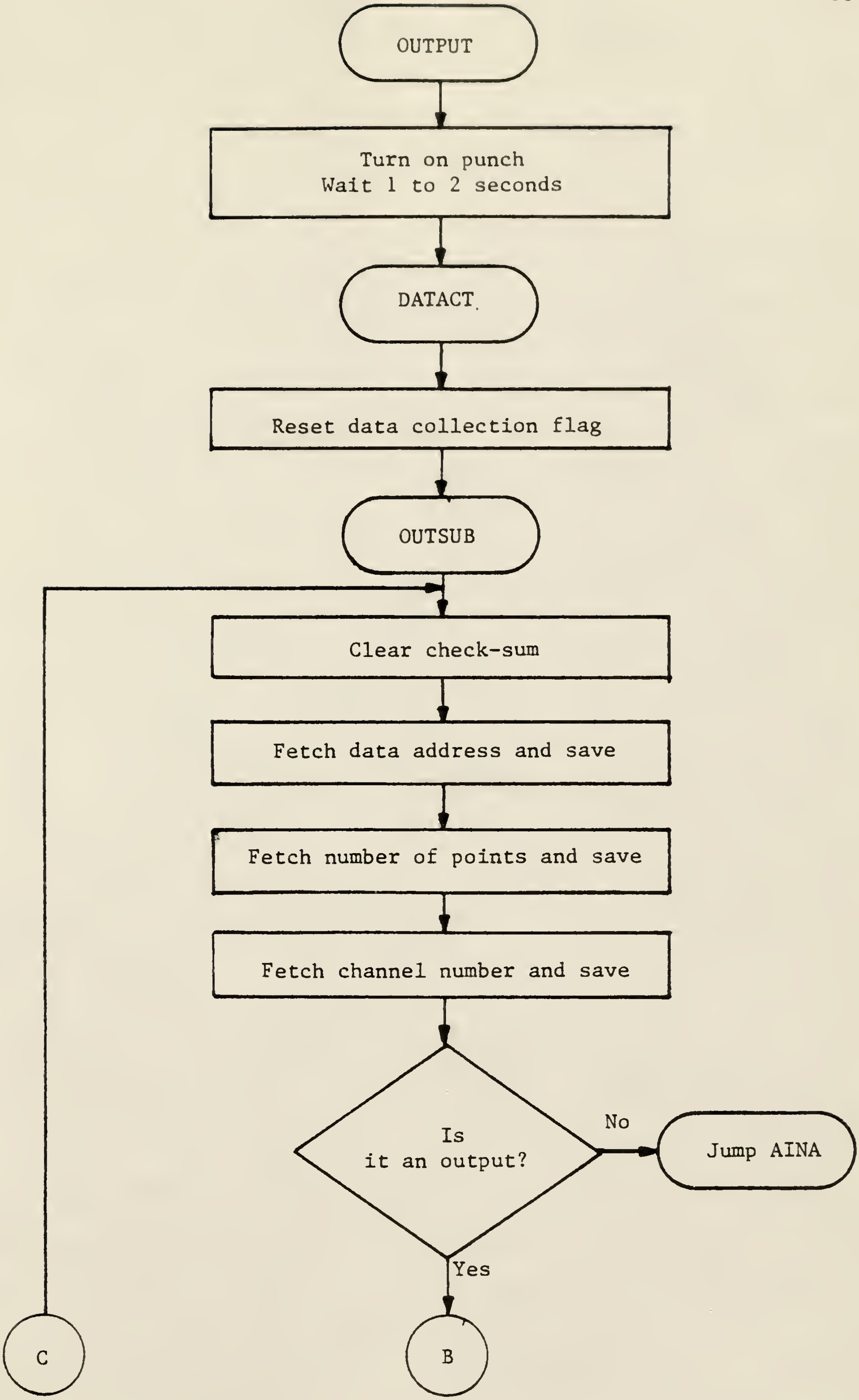
CLEARB — This subroutine clears all memory between Ø8ØØH and 13FFH.

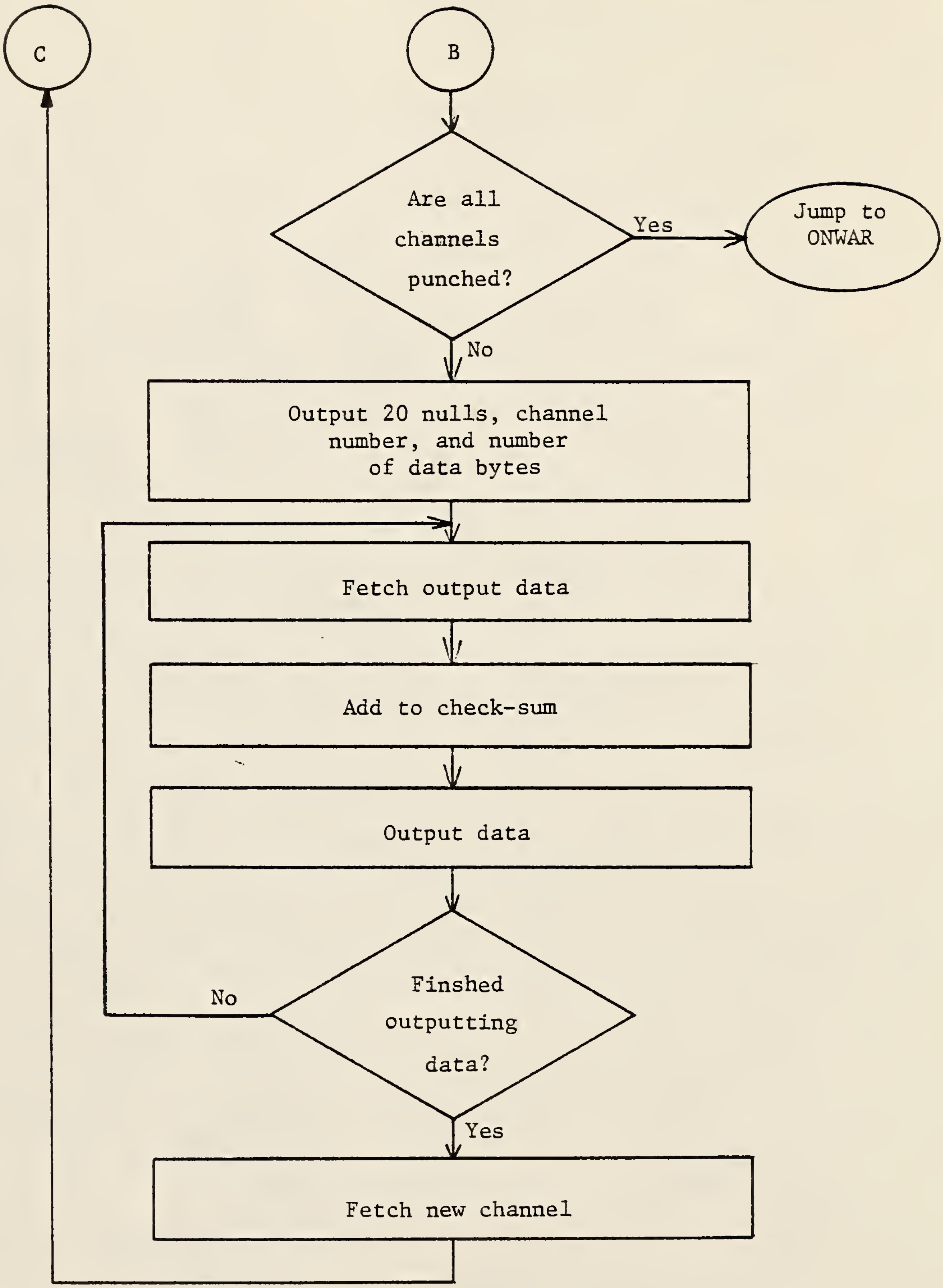


OUTPOK — Subroutine to output the contents of the accumulator to the paper tape punch.

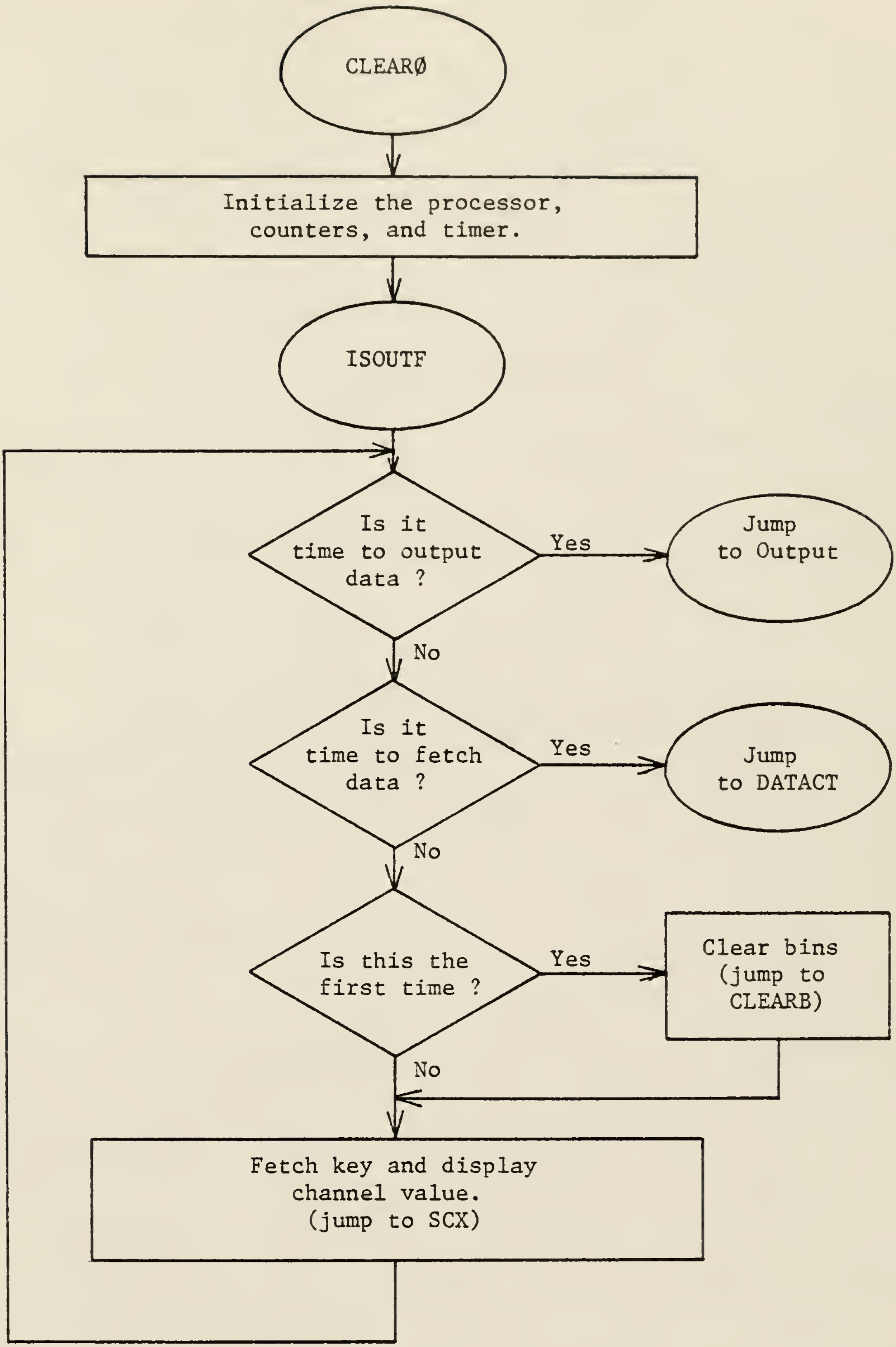


SCX, DIOUT — Subroutines to select and display data on the KIM-1 display.


OUTPUT
Turn on punch
Wait 1 to 2 seconds
DATACT
Reset data collection flag
OUTSUB
Clear check-sum
Fetch data address and save
Fetch number of points and save
Fetch channel number and save
Is
it an output?
No
Jump AINA
Yes
C
B

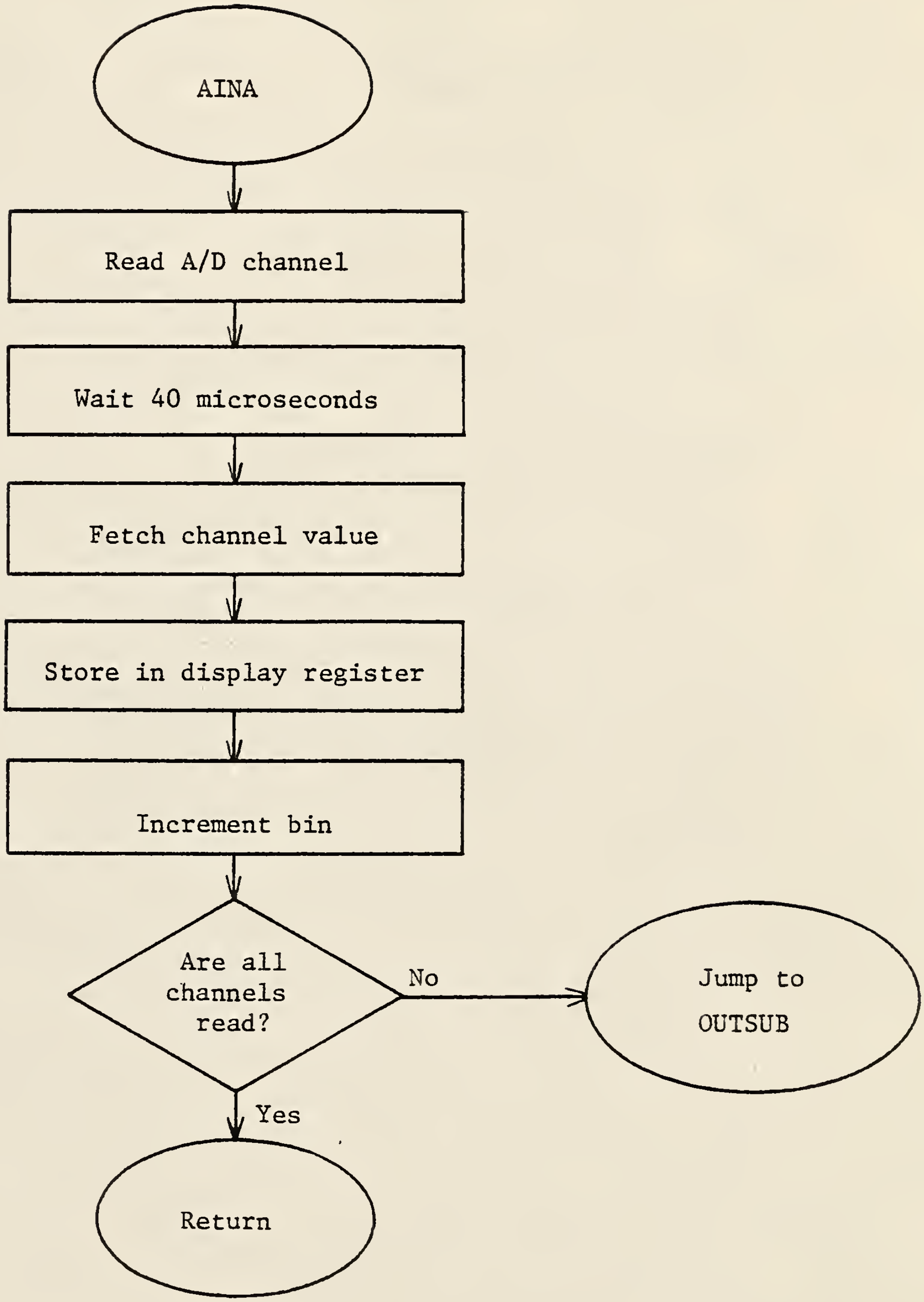


OUTPUT — This routine outputs data to the paper tape punch. It also handles the table for data input.

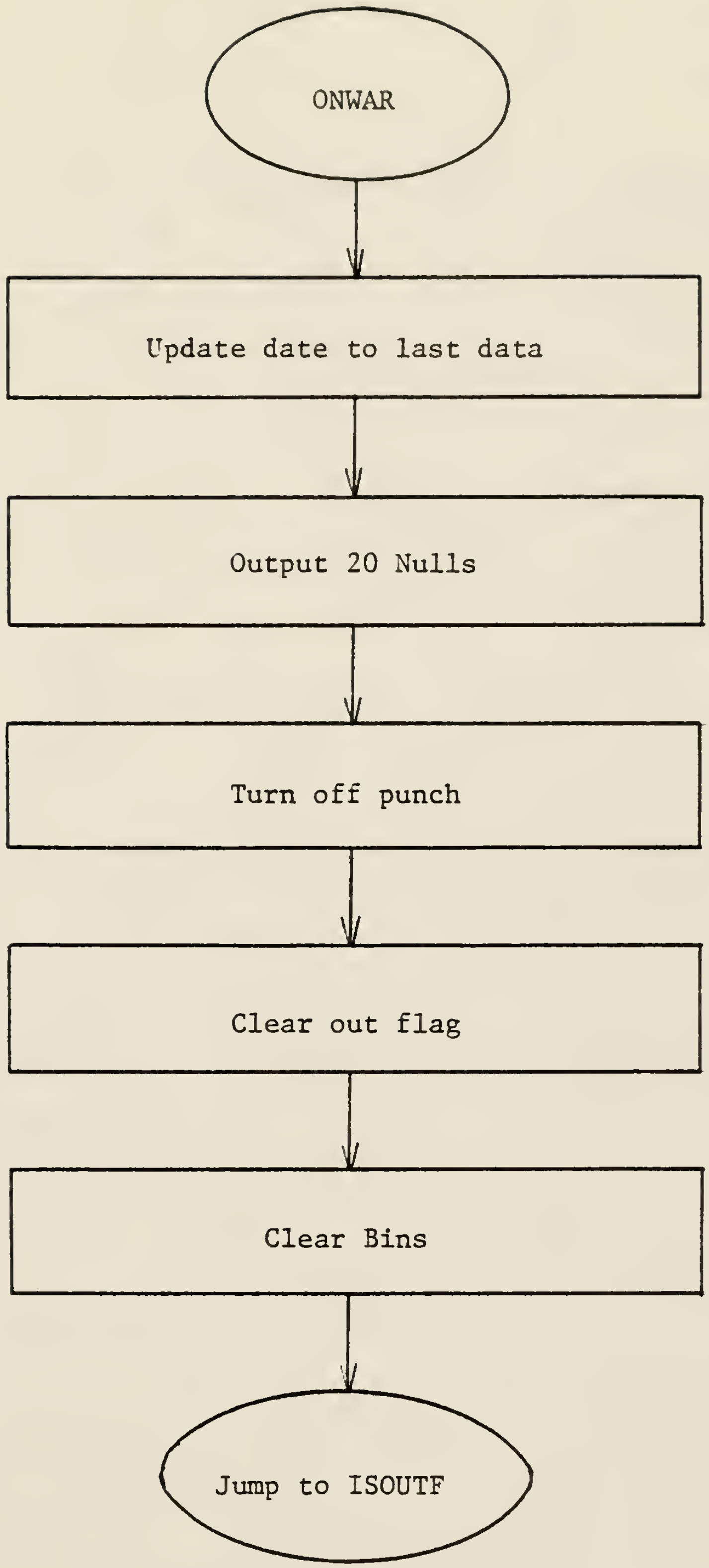


CLEARØ — Initializes the Data Collection System.

ISOUTF — The processor idles in this routine until interrupt.



AINA - This routine reads and fetches data values from the A/D.



ONWAR — This routine turns the punch off, updates time to last time, reinitializes the system and then returns to the main routine.

APPENDIX F

KIM-1 Data Collection Program Listing

The program listing given in this appendix is for both sequential data collection and the method of bins data collection. The listing is ordered from left to right as card number, memory location, code, mnemonic, operand, and comments.

```
LOC    CODE        CARD  10          20        30         40         50
0000            ;
0000            ;                          EQUATES
0000            ;                          SET UP FOR 6502-C2 I/C
0000            ;
0000                  PRA =$1700           PORT A
0000                  DDRA = $1701         DATA DRECTION PORT A
0000                  PRB = $1702          PORT B
0000                  DDRB = $1703         DATA DRECTION PORT B
0000                  TIME = $170F         INTERRUPT TIMER CLOCK
0000                  CHKL = $17E7         CHECK-SUM LOW FOR TAPE OUTPUT
0000                  CHKH = $17E8         CHECK-SUM HIGH
0000                  CHKT = $194C         CHECK-SUM SUBROUTINE KIM
0000                  POINTL = $00FA       OUTPUT TO DISPLAY LOW BYTE
0000                  POINTH = $00FB       OUTPUT TO DISPLAY HIGH BYTE
0000            ;
0000            ;
0000            ;
0000                  *=0
0000  4C 56 04        JMP CLEARO           JUMP TO INITIALIZATION ROUTINES
0003                  SEC6    *=*+1        1/6 SEC COUNTER
0004                  SECN    *=*+1        1 SEC COUNTER
0005                  DAYH    *=*+1        DAY COUNTER HIGH
0006                  DAYL    *=*+1        DAY COUNTER LOW
0007                  HRS     *=*+1        HOURS COUNTER
0008                  MIN     *=*+1        MIN COUNTER
0009                  LDAYH   *=*+1        LAST DAY HIGH
000A                  LDAYL   *=*+1        LAST DAY LOW
000B                  LHRS    *=*+1        LAST HOURS
000C                  LMIN    *=*+1        LAST MIN DATAOUT
000D                  YEAR    *=*+1        YEAR DATE
000E            ;
000E                  C1      *=*+1        TEMPORARY STORAGE FOR
000F                  C2      *=*+1        CHANNELS USED FOR
0010                  C3      *=*+1        KEYBOARD DISPLAY
0011                  C4      *=*+1
0012                  C5      *=*+1
0013                  C6      *=*+1
0014                  C7      *=*+1
0015                  C8      *=*+1
0016                  C9      *=*+1
0017                  C10     *=*+1
0018                  C11     *=*+1
0019                  C12     *=*+1
001A            ;
001A                  OUTF    *=*+1        OUTPUT FLAG WHEN SET OUTPUT DATA
001B                  SECND   *=*+1        1 SEC FLAG SET TO 3CH EVERY SEC.
001C                  DATACF  *=*+1        DATA COLLECTION FLAG
001D                  MUL1H   *=*+1        MULTIPLICAND HIGH BYTE
001E                  MUL1    *=*+1        MULTIPLICAND LOW BYTE
001F                  MUL2    *=*+1        MULTIPLIER
0020                  HIGHMP  *=*+1        HIGH PRODUCT
0021                  LOWMP   *=*+1        LOW PRODUCT
0022                  INF     *=*+1        INPUT FLAG SET FOR DATA READ
0023                  RPM     *=*+1        VALUE OF DIGITAL ANGULAR VELOCITY
0024                  ANEM    *=*+1        VALUE OF DIGITAL ANEMOMETER
```

```
CARD # LOC      CODE        CARD  10          20          30          40          50          60
       0025                          ANEML     *=*+1     LAST VALUE OF ANEM
       0026                          LPAGE     *=*+1     SAVE FOR PAGE ADDRESS LOW BYTE
       0027                          HPAGE     *=*+1     SAVE FOR PAGE ADDRESS HIGH BYTE
       0028                          LONOWP    *=*+1     SAVE FOR PCC LOW
       0029                          HINOWP    *=*+1     SAVE FOR PCC HIGH
       002A                          COUNT     *=*+1     REG. FOR IRQ ROUTINES
       002B                          CHKTC     *=*+1     TEMP. STORAGE FOR CHECK-SUM
       002C                          FIRSTF    *=*+1     FLAG FOR POWER-ON CLEAR BINS IF SET
       002D                          COUNTT    *=*+1     TEMP. REG. OF 40 MICROSEC. DELAY
       002E                   ;
       002E                   ;
       002E                          * = $0200
       0200                   ;
       0200                   ;
       0200                   ;      WAIT40
       0200                   ;
       0200    A9 04          WAIT40  LDA #4             WAIT 40 MICROSEC.
       0202    85 2D                  STA COUNTT         SET COUNTER
       0204    C6 2D          VOL     DEC COUNTT         LOOP COUNT DOWN
       0206    D0 FC                  BNE VOL
       0208    60                     RTS                RETURN
       0209                   ;
       0209                          * = *+5
       020E                   ;
       020E                   ;  NULL20
       020E                   ;  OUTPUT 20 NULLS AND THE ASCII SYNC
       020E    8A             NULL20 TXA                 SAVE X
       020F    48                    PHA
       0210    A2 14                 LDX   #20           SET COUNTER TO 20
       0212    A9 00          NULLNX LDA   #0            LOAD NULLS
       0214    20 3C 03              JSR   OUTPOK        OUTPUT NULL
       0217    CA                    DEX                 DECREMENT COUNTER
       0218    D0 F8                 BNE   NULLNX        DO 20 TIMES
       021A    A9 16                 LDA   #%00010110 ASCII SYNC OUTPUT
       021C    20 3C 03              JSR   OUTPOK
       021F    68                    PLA                 RESTORE X
       0220    AA                    TAX
       0221    60                    RTS
       0222                   ;
       0222                          * = *+5
       0227                   ;
       0227                   ;  IRQ1 INTERRUPTS 6 TIMES PER SECOND
       0227    48             IRQ1    PHA                SAVE CPU ON STACK
       0228    8A                     TXA
       0229    48                     PHA
       022A    98                     TYA
       022B    48                     PHA
       022C    A9 A3                  LDA #$A3           RESET KIM TIMER
       022E    8D 0F 17               STA TIME           INTERRUPT PERIOD=CONTENTS OF TIME/976.56
       0231    20 C8 02               JSR CALEND         UPDATE CALENDER
       0234    A9 00                  LDA #00
       0236    C5 1A                  CMP OUTF           OUTF SET DO NOT FETCH DATA
       0238    D0 05                  BNE PON
       023A    85 1C                  STA DATACF         RESET DATA COLLECTION FLAG
       023C    20 91 02               JSR READ           FETCH DATA
```

```
CARD # LOC    CODE        CARD  10           20           30           40           50           60
       023F   68         PON    PLA
       0240   A8                TAY
       0241   68                PLA
       0242   AA                TAX                RESTORE CPU
       0243   68                PLA
       0244   40                RTI
       0245              ;
       0245                     * = *+5
       024A              ;
       024A              ;  IRQ2 INTERRUPTS  6 TIMES PER SECOND
       024A              ;
       024A   48         IRQ2   PHA                SAVE CPU
       024B   8A                TXA
       024C   48                PHA
       024D   98                TYA
       024E   48                PHA
       024F   A9 A3             LDA #$A3           SET KIM TIMER
       0251   8D 0F 17          STA TIME           INTERRUPT PERIOD=CONTENTS OF TIME/976.56
       0254   85 2A             STA COUNT          SET COUNT FLAG
       0256   68                PLA
       0257   A8                TAY
       0258   68                PLA
       0259   AA                TAX                RESTORE CPU
       025A   68                PLA
       025B   40                RTI                RETURN
       025C              ;
       025C                     * = *+5
       0261              ;
       0261              ;  1 BYTE BY 1 BYTE UNSIGNED MULTIPLY 2 BYTE PRODUCT
       0261              ;
       0261   A9 00      MULT  LDA  #00            MUL2 * MUL1 = PRODUCT
       0263   85 20            STA  HIGHMP         CLEAR PRODUCT HIGH AND LOW
       0265   85 21            STA  LOWMP
       0267   85 1D            STA  MUL1H          CLEAR HIGH BYTE OF MUL1
       0269   AA               TAX                 CLEAR X
       026A   46 1F            LSR  MUL2           SHIFT LEFT MUL2
       026C   B0 0D            BCS  RUN
       026E   E0 07      ITISO CPX  #7
       0270   F0 19            BEQ  DON
       0272   E8               INX
       0273   06 1E            ASL  MUL1
       0275   26 1D            ROL  MUL1H
       0277   46 1F            LSR  MUL2
       0279   90 F3            BCC  ITISO
       027B   A5 1E       RUN  LDA  MUL1
       027D   18               CLC
       027E   65 21            ADC  LOWMP
       0280   85 21            STA  LOWMP
       0282   A5 1D            LDA  MUL1H
       0284   65 20            ADC  HIGHMP
       0286   85 20            STA  HIGHMP
       0288   4C 6E 02         JMP  ITISO
       028B   60         DON   RTS
       028C              ;
       028C                     * = *+5
```

```
LOC      CODE          CARD  10          20          30          40          50          60
0291              ;
0291              ;        READ SUBROUTINE
0291              ;
0291  A5 24        READ LDA   ANEM         FETCH LAST VALUE OF ANEM
0293  85 25             STA   ANEML        STORE AT ANEML
0295  A9 00             LDA   #00          SET A PORT AS A INPUT
0297  8D 01 17          STA   DDRA
029A  A9 10             LDA   #$10         INHIBIT DIGITAL COUNTERS
029C  8D 02 17          STA   PRB          AND SELECT RPM COUNT
029F  AD 00 17          LDA   PRA          FETCH RPM COUNT
02A2  85 23             STA   RPM          STORE AT RPM
02A4  A9 20             LDA   #$20         SELECT ANEM COUNTER
02A6  8D 02 17          STA   PRB
02A9  AD 00 17          LDA   PRA          FETCH ANEM COUNT
02AC  85 24             STA   ANEM         STORE AT ANEM
02AE  A9 23             LDA   #$23         RESET COUNTER AND
02B0  8D 02 17          STA   PRB          RELEASE INHIBIT
02B3  A9 21             LDA   #$21         GO COUNT
02B5  8D 02 17          STA   PRB          LEAVE FOR PUNCH
02B8              ;  IF THRESHOLD IS GREATER THAN ANGULAR VELOCITY DO NOT COLLECT
02B8  A5 23             LDA RPM            ANGULAR VELOCITY LOAD
02BA              ;  THRESHOLD IS DEFINED AS THE CMP #THRESHOLD
02BA  C9 00             CMP #00            COMPARE ANGULAR VELOCITY TO THRESHOLD
02BC  90 04             BCC NOCOL          IF RPM < THRESHHOLD DO NOT COLLECT DATA
02BE  A9 01             LDA #1
02C0  85 1C             STA DATACF         SET DATA COLLECTION FLAG
02C2  60           NOCOL RTS               RETURN
02C3              ;
02C3                    * = *+5
02C8              ;
02C8              ;   CALEND
02C8              ;
02C8  A9 06       CALEND LDA #6
02CA  A2 00             LDX   #0           INCREMENT 1/6 SEC
02CC  E6 03             INC   SEC6         REGISTER
02CE  C5 03             CMP   SEC6         WHEN =1 SEC
02D0  F0 01             BEQ   ASEC         BRANCH TO ASEC
02D2  60                RTS
02D3  86 03       ASEC  STX   SEC6         CLEAR SEC6
02D5  E6 04             INC   SECN         INCREMENT SEC
02D7  A9 3C             LDA   #60
02D9  85 13             STA   SECND        SET FLAG FOR PUNCH POWER-UP
02DB  C5 04             CMP   SECN         WHEN = 60
02DD  F0 01             BEQ   AMIN         BRANCH
02DF  60                RTS
02E0  86 04       AMIN  STX   SECN         ETC.
02E2  E6 08             INC   MIN
02E4  C5 08             CMP   MIN
02E6  F0 01             BEQ   AHRS
02E8  60                RTS
02E9  86 08       AHRS  STX   MIN
02EB  E6 07             INC   HRS
02ED  A9 18             LDA   #24
02EF  C5 07             CMP   HRS
02F1  F0 01             BEQ   ADAY
```

```
CARD # LOC    CODE          CARD  10          20          30          40          50          60
       02F3   60                  RTS
       02F4   86 07       ADAY  STX   HRS
       02F6   A5 06             LDA   DAYL
       02F8   18                CLC
       02F9   69 01             ADC   #1
       02FB   85 06             STA   DAYL
       02FD   A5 05             LDA   DAYH
       02FF   69 00             ADC   #00
       0301   85 05             STA   DAYH
       0303   60                RTS
       0304               ;
       0304               ;
       0304                       * = *+5
       0309               ; CLEARB
       0309               ;
       0309   A9 08       CLEARB  LDA #$08        CLEAR ALL MEMORY BETWEEN 080CH AND 13FFH
       030B   8D 15 03            STA THERE+2
       030E   A0 14               LDY #$14        STOP CLEAR AT 13FFH
       0310   A9 00       FEB     LDA #00         CLEAR ACCUM.
       0312   AA                  TAX             CLEAR X
       0313   9D 00 08     THERE  STA $0800,X     CLEAR PAGE,X
       0316   E8                  INX             CLEAR NEXT X
       0317   E0 00               CPX #00         CLEAR ALL 256
       0319   D0 F8               BNE THERE       DO NEXT PAGE
       031B   EE 15 03            INC THERE+2
       031E   CC 15 03            CPY THERE+2     FINSHED AT PAGE 14
       0321   D0 ED               BNE FEB
       0323   60                  RTS             RETURN
       0324               ;
       0324                       * = *+5
       0329               ;
       0329               ; INCPPC
       0329               ; INCREMENTS PC ON STACK(PPC), LONOWP, CARRY ADDED TO HINOWP
       0329   A5 28       INCPPC LDA  LONOWP      FETCH VALUE IN
       032B   18                CLC               LONOWP ADD 1
       032C   69 01             ADC   #1          AND SAVE
       032E   85 28             STA   LONOWP      FETCH VALUE IN
       0330   A5 29             LDA   HINOWP      HINOWP ADD
       0332   69 00             ADC   #00         CARRY AND
       0334   85 29             STA   HINOWP      SAVE
       0336   60                RTS
       0337               ;
       0337                       * = *+5
       033C               ;
       033C               ;    OUTPOK
       033C               ;
       033C               ;  USES ACCUM
       033C               ;  SUBROUTINE USED IN OUTPUT TO PUNCH
       033C               ;  LOAD DATA REGISTERS IN OUTPUT PORT
       033C   8D 00 17    OUTPOK STA PRA          OUTPUT DATA IN ACCUM
       033F   A9 08             LDA   #$08        LOAD PUNCH COMMAND
       0341   8D 02 17          STA   PRB
       0344   A9 01             LDA   #1          STOP PUNCH COMMAND
       0346   8D 02 17          STA   PRB
       0349   AD 02 17    BUSY  LDA   PRB         FETCH BUSY
```

```
CARD # LOC     CODE          CARD  10           20          30          40          50
       034C   29 04               AND   #%0000100   MASK ALL BUT BUSY
       034E   F0 F9               BEQ   BUSY        IF BUSY TEST AGAIN
       0350   EA                  NOP               WAIT AFTER BUSY FOR
       0351   EA                  NOP               PUNCH
       0352   60                  RTS               RETURN
       0353                 ;
       0353                         * = *+5
       0358                 ;
       0358                 ; SCX SUBROUTINES (KEYBOARD)
       0358                 ; THESE SUBROUTINES SELECT THE OUTPUT DISPLAYED VALUE
       0358                 ;
       0358   A9 BB         SC0      LDA #$BB
       035A   A2 BA                  LDX #$BA
       035C   4C CD 03               JMP DISOUT
       035F   A5 0E         SC1      LDA C1
       0361   A2 00                  LDX #0
       0363   4C CD 03               JMP DISOUT
       0366   A5 0F         SC2      LDA C2
       0368   A2 00                  LDX #0
       036A   4C CD 03               JMP DISOUT
       036D   A5 10         SC3      LDA C3
       036F   A2 00                  LDX #0
       0371   4C CD 03               JMP DISOUT
       0374   A5 11         SC4      LDA C4
       0376   A2 00                  LDX #0
       0378   4C CD 03               JMP DISOUT
       037B   A5 12         SC5      LDA C5
       037D   A2 00                  LDX #0
       037F   4C CD 03               JMP DISOUT
       0382   A5 13         SC6      LDA C6
       0384   A2 00                  LDX #0
       0386   4C CD 03               JMP DISOUT
       0389   A5 14         SC7      LDA C7
       038B   A2 00                  LDX #0
       038D   4C CD 03               JMP DISOUT
       0390   A5 15         SC8      LDA C8
       0392   A2 00                  LDX #0
       0394   4C CD 03               JMP DISOUT
       0397   A5 24         SC9      LDA ANEM
       0399   A2 00                  LDX #0
       039B   4C CD 03               JMP DISOUT
       039E   A5 17         SC10     LDA C10
       03A0   A2 00                  LDX #0
       03A2   4C CD 03               JMP DISOUT
       03A5   A5 23         SC11     LDA RPM
       03A7   A2 00                  LDX #0
       03A9   4C CD 03               JMP DISOUT
       03AC   A5 19         SC12     LDA C12
       03AE   A2 00                  LDX #0
       03B0   4C CD 03               JMP DISOUT
       03B3   A5 06         SC13     LDA DAYL
       03B5   A6 05                  LDX DAYH
       03B7   4C CD 03               JMP DISOUT
       03BA   A5 07         SC14     LDA HRS
       03BC   A2 00                  LDX #0
```

```
 LOC    CODE        CARD  10               20              30              40              50              60
 03BE   4C CD 03              JMP DISOUT
 03C1   A5 08       SC15      LDA MIN
 03C3   A2 00                 LDX #0
 03C5   4C CD 03              JMP DISOUT
 03C8               ;
 03C8                         *=*+5
 03CD               ;
 03CD   85 FA       DISOUT    STA $FA             ACCUM TO KIM POINTL
 03CF   86 FB                 STX $FB             X TO POINTH
 03D1   20 19 1F              JSR $1F19           KIM DISPLAY
 03D4   4C 70 04              JMP ISOUTF
 03D7               ;
 03D7                         * = *+5
 03DC               ;
 03DC               ; THIS ROUTINE ORDERS THE DATA COLLECTION AND OUTPUT
 03DC   A9 00       OUTSUB LDA #0             CLEAR CHECK-SUM
 03DE   8D E8 17              STA CHKH
 03E1   8D E7 17              STA CHKL
 03E4   68                    PLA                 FETCH PCL FROM STACK
 03E5   85 28                 STA LONOWP          SAVE IN LONOWP
 03E7   68                    PLA                 FETCH PCH FROM STACK
 03E8   85 29                 STA HINOWP          SAVE HINOWP
 03EA   20 29 03              JSR INCPPC          INCREMENT PPC; PPC IS FALSE PROGRAM COUNTER
 03ED   A0 00                 LDY #00             AT LOCATION HINOWP AND LONOWP
 03EF   B1 28                 LDA (LONOWP),Y      FETCH HIGH BYTE PAGE
 03F1   85 27                 STA HPAGE           SAVE HIGH BYTE
 03F3   20 29 03              JSR INCPPC
 03F6   B1 28                 LDA (LONOWP),Y      FETCH LOW BYTE PAGE
 03F8   85 26                 STA LPAGE           SAVE LOW BYTE
 03FA   20 29 03              JSR INCPPC
 03FD   B1 28                 LDA (LONOWP),Y      FETCH NUMBER OF DATA POINTS -1
 03FF   AA                    TAX                 SAVE X
 0400   20 29 03              JSR INCPPC
 0403   B1 28                 LDA (LONOWP),Y      FETCH CHANNEL NO.
 0405   A8                    TAY                 SAVE IN Y REG
 0406   A5 29                 LDA HINOWP          FETCH HIGH PPC
 0408   48                    PHA                 PUT ON STACK
 0409   A5 28                 LDA LONOWP          FETCH LOW PPC
 040B   48                    PHA                 PUT ON STACK
 040C   A9 00                 LDA #00
 040E   C5 22                 CMP INF             IF DATA COLLECTION TIME JUMP TO AINA
 0410   F0 03                 BEQ FURTH
 0412   4C C8 05              JMP AINA
 0415   C0 FF       FURTH     CPY #$FF            IF Y=FFH ALL BINS OR DATA ARE OUTPUT
 0417   D0 03                 BNE WITH            JUMP TO ONWAR AND UPDATE TIME TO LAST TIME
 0419   4C 97 05              JMP ONWAR
 041C   20 0E 02    WITH      JSR NULL20          OUTPUT NULLS AND SYNC
 041F   98                    TYA                 MOVE CHANNEL NO. TO ACCUM
 0420   20 3C 03              JSR OUTPCK          OUTPUT CHANNEL NO.
 0423   8A                    TXA                 MOVE NUMBER OF DATA POINT-1
 0424   18                    CLC
 0425   69 01                 ADC #1              INCREMENT ACCUM
 0427   A8                    TAY                 NO. OF DATAPOINTS
 0428   A9 00                 LDA #00
 042A   69 00                 ADC #00
```

```
LOC     CODE          CARD  10         20          30          40          50          60
042C  20 3C 03              JSR OUTPOK          OUTPUT HIGHBYTE
042F  98                    TYA                 DATA POINTS
0430  20 3C 03              JSR OUTPOK          OUTPUT LOW BYTE
0433  88                    DEY
0434  B1 26         STATE   LDA (LPAGE),Y
0436  84 2B                 STY CHKTC           SAVE
0438  20 4C 19              JSR CHKT            COMPUTE CHECK-SUM
043B  A4 2B                 LDY CHKTC           RESTORE Y
043D  20 3C 03              JSR OUTPOK          OUTPUT VALUE
0440  C0 00                 CPY #0              IF Y IS 0
0442  D0 EF                 BNE STATE-1         FINSHED
0444  AD E8 17              LDA CHKH            OUTPUT HIGH CHECK-SUM
0447  20 3C 03              JSR OUTPOK
044A  AD E7 17              LDA CHKL            OUTPUT LOW CHECK-SUM
044D  20 3C 03              JSR OUTPOK
0450  60                    RTS
0451                ;
0451                        * = *+5
0456                ;
0456  A9 00         CLEARO   LDA #0             CLEAR ACCUM
0458  48                     PHA                CLEAR PROCESSOR STATUS
0459  28                     PLP
045A  85 2C                  STA FIRSTF         RESET FIRST TIME FLAG
045C  20 09 03               JSR CLEARB         CLEAR BINS
045F  A9 FF         BACK     LDA #$FF           SET A PORT AS ALL
0461  8D 01 17               STA DDRA           OUTPUTS
0464  A9 21                  LDA #$21           TURN PUNCH OFF RESET COUNTERS
0466  8D 02 17               STA PRB
0469  A9 3B                  LDA #$3B           SET PORT B
046B  8D 03 17               STA DDRB
046E  A9 A3                  LDA #$A3           RESET KIM COUNTER TO 1/6 SEC
0470  8D 0F 17               STA TIME
0473                         MOS=IRQ1/256*256
0473  A9 27                  LDA #IRQ1-MOS      LOW BYTE OF IRQ1
0475  8D FE 17               STA $17FE          STORE IN IRQ VECTOR
0478  A9 02                  LDA #IRQ1/256      HIGH BYTE OF IRQ1
047A  8D FF 17               STA $17FF          STORE IN IRQ VECTOR
047D  A9 00         ISOUTF   LDA #00            IF OUTF IS SET GO TO OUTPUT
047F  C5 1A                  CMP OUTF
0481  F0 03                  BEQ FETCH
0483  4C 1C 05               JMP OUTPUT
0486  A5 1C         FETCH    LDA DATACF         IF DATA COLLECTION TIME- COLLECT DATA
0488  C9 01                  CMP #1
048A  D0 0E                  BNE GETKEY         FETCH KEY
048C  20 B9 05               JSR DATACT
048F  A9 01                  LDA #1
0491  C5 2C                  CMP FIRSTF         IF FIRST TIME CLEAN BINS
0493  F0 05                  BEQ GETKEY         THIS RESET COUNTERS
0495  85 2C                  STA FIRSTF         RESET FLAG TO BRANCH NEXT TIME
0497  20 09 03               JSR CLEARB         CLEAR BINS
049A  20 6A 1F      GETKEY JSR $1F6A            KIM GETKEY
049D  C9 10                CMP #16              MUST BE < 15 TO
049F  30 03                BMI KEY              BE VALID
04A1  4C 7D 04             JMP ISOUTF           IF NOT VALID
04A4  C9 00         KEY    CMP  #0              IF ZERO JUMP TO SUBROUTINE FOR CO
```

PAGE

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CARD # LOC     CODE         CARD  10           20           30           40           50
       04A6   D0 03                BNE   NEXT1
       04A8   4C 58 03             JMP   SC0
       04AB   C9 01       NEXT1 CMP   #1
       04AD   D0 03                BNE   NEXT2
       04AF   4C 5F 03             JMP SC1                  JUMP TO SUBROUTINE C1  ETC.
       04B2   C9 02       NEXT2 CMP   #2
       04B4   D0 03                BNE   NEXT3
       04B6   4C 66 03             JMP   SC2
       04B9   C9 03       NEXT3 CMP   #3
       04BB   D0 03                BNE   NEXT4
       04BD   4C 6D 03             JMP   SC3
       04C0   C9 04       NEXT4 CMP   #4
       04C2   D0 03                BNE   NEXT5
       04C4   4C 74 03             JMP   SC4
       04C7   C9 05       NEXT5 CMP   #5
       04C9   D0 03                BNE   NEXT6
       04CB   4C 7B 03             JMP   SC5
       04CE   C9 06       NEXT6 CMP   #6
       04D0   D0 03                BNE   NEXT7
       04D2   4C 82 03             JMP   SC6
       04D5   C9 07       NEXT7 CMP   #7
       04D7   D0 03                BNE   NEXT8
       04D9   4C 89 03             JMP   SC7
       04DC   C9 08       NEXT8 CMP   #8
       04DE   D0 03                BNE   NEXT9
       04E0   4C 90 03             JMP   SC8
       04E3   C9 09       NEXT9 CMP   #9
       04E5   D0 03                BNE   NEXT10
       04E7   4C 97 03             JMP   SC9
       04EA   C9 0A       NEXT10 CMP   #10
       04EC   D0 03                 BNE   NEXT11
       04EE   4C 9E 03              JMP   SC10
       04F1   C9 0B       NEXT11 CMP   #11
       04F3   D0 03                 BNE   NEXT12
       04F5   4C A5 03              JMP   SC11
       04F8   C9 0C       NEXT12 CMP   #12
       04FA   D0 03                 BNE   NEXT13
       04FC   4C AC 03              JMP   SC12
       04FF   C9 0D       NEXT13 CMP   #13
       0501   D0 03                 BNE   NEXT14
       0503   4C B3 03              JMP   SC13
       0506   C9 0E       NEXT14 CMP   #14
       0508   D0 03                 BNE   NEXT15
       050A   4C BA 03              JMP   SC14
       050D   C9 0F       NEXT15 CMP   #15              IF KEY NOT 0 TO 15
       050F   D0 03                 BNE   NEXT16
       0511   4C C1 03              JMP   SC15              MUST BE ERROR
       0514   4C 00 1C    NEXT16 JMP   $1C00             JUMP TO KIM MONITOR
       0517               ;
       0517               ;
       0517               ;
       0517                       * = *+5
       051C               ;
       051C               ;OUTPUT DATA TO PUNCH
       051C               ;
```

PAGE 10

```
CARD # LOC    CODE       CARD  10       20          30         40         50
051C  A9 FF       OUTPUT LDA $$FF       PORT A AS AN OUTPUT
051E  8D 01 17           STA DDRA       FOR PUNCH
0521  A9 00              LDA #00        TURN ON PUNCH
0523  85 22              STA INF        CLEAR IN FLAG
0525  8D 02 17           STA PRB
0528              ;WAIT FOR 1 TO 2 SEC FOR PUNCH TO COME UP
0528  85 1B              STA SECND      RESET SECONDS FLAG
052A  C5 1B       WAIMR  CMP SECND      SEE IF FLAG IS SET
052C  F0 FC              BEQ WAIMR      IF IT IS GO ON
052E  85 1B              STA SECND      RESET SECONDS FLAG
0530  C5 1B       WAISMR CMP SECND      SEE IF FLAG IS SET
0532  F0 FC              BEQ WAISMR     GO ON AFTER 1 TO 2 SEC
0534              ;
0534              ;
0534  EA          OUT    NOP
0535              ;OUTPUT ANALOG ANEMOMETER 1
0535  20 DC 03           JSR OUTSUB
0538  13 00              .DBYTE $1300
053A  FF                 .BYTE 255
053B  01                 .BYTE 1
053C              ;OUTPUT TORQUE
053C  20 DC 03           JSR OUTSUB
053F  12 00              .DBYTE $1200
0541  FF                 .BYTE 255
0542  02                 .BYTE 2
0543              ; OUTPUT ALTERNATOR VOLTAGE
0543  20 DC 03           JSR OUTSUB
0546  10 00              .DBYTE $1000
0548  FF                 .BYTE 255
0549  04                 .BYTE 4
054A              ; OUTPUT WIND DIRECTION
054A  20 DC 03           JSR OUTSUB
054D  0F 00              .DBYTE $0F00
054F  FF                 .BYTE 255
0550  05                 .BYTE 5
0551              ; OUTPUT AIR TEMP
0551  20 DC 03           JSR OUTSUB
0554  00 13              .DBYTE C6
0556  C0                 .BYTE 0
0557  C6                 .BYTE 6
0558              ; OUTPUT AIR PRESSURE
0558  20 DC 03           JSR OUTSUB
055B  00 14              .DBYTE C7
055D  C0                 .BYTE 0
055E  C7                 .BYTE 7
055F              ;  OUTPUT ANALOG ANEMOMETER 2
055F  20 DC 03           JSR OUTSUB
0562  0C 00              .DBYTE $0C00
0564  FF                 .BYTE 255
0565  08                 .BYTE 8
0566              ; OUTPUT ANGULAR VELOCITY
0566  20 DC 03           JSR OUTSUB
0569  0B 00              .DBYTE $0B00
056B  FF                 .BYTE 255
056C  0B                 .BYTE 11
```

```
CARD # LOC    CODE        CARD   10           20          30           40          50
       05C3  48                  PHA                      PUT ON STACK FOR RTS
       05C4                      BAT=OUT/256*256
       05C4  A9 34               LDA #OUT-BAT             LOW VALUE FIRST OUTPUT ADDRESS-1
       05C6  48                  PHA                      PUT ON STACK FOR RTS
       05C7  60          SCALE   RTS                      FETCH NEW CHANNEL OFF STACK
       05C8  98          AINA    TYA
       05C9  C9 06               CMP #6                   JUMP HERE FROM OUTSUB
       05CB  90 03               BCC CNMOR                6 IS FIRST CHANNEL NOT BEING BINNED
       05CD  4C F0 05            JMP CCMPUT
       05D0  AA          CNMOR   TAX
       05D1  CA                  DEX                      CHANNEL NUMBER-1 = ADDRESS
       05D2  BD 00 14            LDA $1400,X              START CONVERSION
       05D5  20 00 02            JSR WAIT40               WAIT FOR CONVERSION
       05D8  BD 00 14            LDA $1400,X              FETCH VALUE
       05DB  95 0E               STA C1,X                 SAVE VALUE IN TEMP. STORAGE
       05DD  A8          INCBIN  TAY                      INCREMENTS BINS, VALUE READ IN Y
       05DE  B1 26               LDA (LPAGE),Y            FETCH BIN LOCATION
       05E0  18                  CLC
       05E1  69 01               ADC #1
       05E3  91 26               STA (LPAGE),Y            STORE AT SAME LOCATION
       05E5  C9 FF               CMP #$FF                 COMPARE FOR FULL BIN
       05E7  90 DE               BCC SCALE
       05E9  A9 01               LDA #1                   JUMP TO SCALE  SETTING OUTF
       05EB  85 1A               STA OUTF                 IF BIN IS FULL
       05ED  4C C7 05            JMP SCALE
       05F0  C9 09       CCMPUT  CMP #9                   IF CHANNEL NO. IS 9
       05F2  D0 05               BNE CNNOW1
       05F4  A5 24               LDA ANEM
       05F6  4C DD 05            JMP INCBIN
       05F9  C9 0A       CNNOW1  CMP #10                  IF CHANNEL 10 INCREMENT BIN
       05FB  D0 0F               BNE CNNOW2               FOR DELTA ANEM
       05FD  A5 24               LDA ANEM
       05FF  38                  SEC
       0600  E5 25               SBC ANEML                ANEM-ANEML = DELTA WIND
       0602  90 05               BCC LESS                 IF ANEML > ANEM BRANCH
       0604  85 17               STA C10                  TO LESS
       0606  4C DD 05            JMP INCBIN               IF NOT INCBIN
       0609  4C C7 05    LESS    JMP SCALE                GET NEW CHANNEL
       060C  C9 0B       CNNOW2  CMP #11
       060E  D0 05               BNE CNNOW3
       0610  A5 23               LDA RPM
       0612  4C DD 05            JMP INCBIN
       0615  C9 0C       CNNOW3  CMP #12
       0617  D0 32               BNE CNNOW4               COMPUTE POWER
       0619  A5 23               LDA RPM                  FETCH RPM COUNT
       061B  85 1E               STA MUL1                 STORE MULTIPLICAND
       061D  A5 0F               LDA C2                   FETCH TORQUE
       061F  85 1F               STA MUL2                 STORE MULTIPLIER
       0621  20 61 02            JSR MULT                 COMPUTE POWER P=TW
       0624  A5 20               LDA HIGHMP               SAVE HIGH BYTE
       0626  48                  PHA
       0627  A5 21               LDA LOWMP                SAVE LOW BYTE
       0629  48                  PHA
       062A  18                  CLC
       062B  A5 23               LDA RPM                  FETCH RPM AND ADD 1
```

```
LOC     CODE          CARD  10              20             30             40             50             60
056D                ; OUTPUT MECHANICAL POWER
056D    20 DC 03            JSR OUTSUB
0570    C8 00               .DBYTE $0800
0572    FF                  .BYTE 255
0573    0C                  .BYTE 12
0574                ; OUTPUT TIME
0574    20 DC 03            JSR OUTSUB
0577    C0 05               .DBYTE DAYH
0579    C8                  .BYTE 8
057A    CD                  .BYTE 13
057B                ; FINSHED
057B                ; PUT THIS MACRO LAST AFTER ALL CHANNELS OUTPUT OR COLLECTED
057B    20 DC 03            JSR OUTSUB
057E    C0 00               .DBYTE 00
0580    C0                  .BYTE 00
0581    FF                  .BYTE  $FF
0582                ;
0582                ; OUTPUT ELECTRICAL POWER
0582    20 DC 03            JSR OUTSUB
0585    11 00               .DBYTE $1100
0587    FF                  .BYTE 255
0588    03                  .BYTE 3
0589                ; OUTPUT DIGITAL ANEMOMETER
0589    20 DC 03            JSR OUTSUB
058C    CA C0               .DBYTE $0A00
058E    FF                  .BYTE 255
058F    09                  .BYTE 9
0590                ; OUTPUT DELTA WIND SPEED
0590    20 DC 03            JSR OUTSUB
0593    C9 00               .DBYTE $0900
0595    FF                  .BYTE 255
0596    0A                  .BYTE 10
0597                ;
0597    A5 08       ONWAR   LDA MIN
0599    85 0C               STA LMIN
059B    A5 07               LDA HRS
059D    85 08               STA LHRS
059F    A5 05               LDA DAYH
05A1    85 09               STA LDAYH
05A3    A5 06               LDA DAYL
05A5    85 0A               STA LDAYL
05A7    20 0E 02            JSR NULL20      OUT 20 NULLS AND SYNC
05AA    A9 21               LDA #$21        TURN OFF PUNCH
05AC    8D 02 17            STA PRB
05AF    A9 00               LDA #00         CLEAR OUT FLAG
05B1    85 1A               STA OUTF
05B3    20 C9 03            JSR CLEARB      CLEAR BINS
05B6    4C 7D 04            JMP ISOUTF      RETURN
05B9                ;
05B9                ; THIS ROUTINE ADJUST THE STACK FOR OUTPUT
05B9    A9 00       DATACT   LDA #0
05BB    85 1C                STA DATACF     RESET DATACF
05BD    A9 01                LDA #1         SET INFLAG
05BF    85 22                STA INF
05C1    A9 05                LDA #OUT/256   HIGH BYTE FIRST OUTPUT ADDRESS-1
```

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CARD # LOC    CODE          CARD   10              20          30          40          50
       06A0   8D FF 17             STA $17FF               STORE INTERRUPT VECTOR LOCATION
       06A3   A9 21                LDA #$21                TURN PUNCH OFF AND SET COUNTER
       06A5   8D 02 17             STA PRB
       06A8   A9 3B                LDA #$3B
       06AA   8D 03 17             STA DDRB                SET B AS INPUT/OUTPUT
       06AD   A9 62                LDA #$62                SET KIM TIMER
       06AF   8D 0F 17             STA TIME
       06B2   A9 02        START   LDA #2                  FETCH DATA TWICE
       06B4   C5 2C                CMP FIRSTF              AND CLEAR BINS
       06B6   F0 04                BEQ THIRD               MAKES COUNTER 1ST DATA GOOD
       06B8   E6 2C                INC FIRSTF
       06BA   A2 00                LDX #00
       06BC   85 2A        THIRD   STA COUNT
       06BE   C5 2A        ME      CMP COUNT               WAIT FOR INTERRUPT TO SET COUNT
       06C0   F0 FC                BEQ ME                  WHEN CHANGED COLLECT DATA
       06C2   A9 10                LDA #$10                SELECT RPM COUNTER
       06C4   8D 02 17             STA PRB
       06C7   AD 00 17             LDA PRA                 FETCH ANGULAR VELOCITY
       06CA   9D 00 08             STA $0800,X             STORE RPM COUNT
       06CD   A9 20                LDA #$20                SELECT ANEM DIGITAL COUNT
       06CF   8D 02 17             STA PRB
       06D2   AD 00 17             LDA PRA                 FETCH ANEM DIGITAL COUNT
       06D5   9D 00 0A             STA $0A00,X             STA ANEM
       06D8   A9 23                LDA #$23                RESET COUNTER
       06DA   8D 02 17             STA PRB
       06DD   A9 21                LDA #$21                RELEASE INHIBIT GO COUNT
       06DF   8D 02 17             STA PRB
       06E2   A0 00                LDY #00                 CLEAR FOR MP21 CHANNEL
       06E4   A9 13                LDA #$13                LDA HIGH BIN
       06E6   8D F4 06             STA LOP3+2              STORE IN ADDRESS LOC
       06E9   B9 00 14     LOP4    LDA $1400,Y             START CONVERSION
       06EC   20 00 02             JSR WAIT40              WAIT
       06EF   B9 00 14             LDA $1400,Y             FETCH VALUE
       06F2   9D 00 13     LOP3    STA $1300,X             STORE IN MEMORY
       06F5   C8                   INY                     SET NEXT CHANNEL
       06F6   CE F4 06             DEC LOP3+2              SET NEXT LOWER PAGE
       06F9   C0 08                CPY #8                  DO ALL CHANNELS OF MP21
       06FB   D0 EC                BNE LOP4
       06FD   E8                   INX                     DO 256 SAMPLES
       06FE   E0 00                CPX #00
       0700   D0 B0                BNE START
       0702   AD 05 14             LDA $1405               DO CHANNEL MP21 5 TEMP
       0705   20 00 02             JSR WAIT40
       0708   AD 05 14             LDA $1405
       070B   85 13                STA C6                  STORE TEMP.
       070D   AD 06 14             LDA $1406               DO CHANNEL MP21 6 PRESSURE.
       0710   20 00 02             JSR WAIT40
       0713   AD 06 14             LDA $1406
       0716   85 14                STA C7                  STORE VALUE
       0718   A9 01                LDA #1                  SET OUT FLAG
       071A   85 1A                STA OUTF
       071C   4C 5F 04             JMP BACK                JUMP TO IS OUT FLAG SET
```

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CARD # LOC      CODE          CARD  10          20          30
  769  071F                         .END


END OF MOS/TECHNOLOGY 650X ASSEMBLY VERSION 5
NUMBER OF ERRORS =    0,  NUMBER OF WARNINGS =    0
```

SYMBOL TABLE

SYMBOL	VALUE	LINE DEFINED	CROSS-REFERENCES									
ADAY	02F4	222	220									
AHRS	02E9	216	214									
AINA	05C8	611	373									
AMIN	02E0	211	209									
ANEM	0024	55	169	180	314	633	637					
ANEML	0025	56	170	639								
ARE	02C0	712	713									
ASEC	02D3	204	202									
BACK	045F	410	767									
BAT	05C0	607	608									
BUSY	0349	275	277									
CALEND	02C8	198	105									
CHKH	17E8	11	347	397								
CHKL	17E7	10	348	399								
CHKT	194C	12	392									
CHKTC	0028	62	391	393								
CLEARB	0309	236	409	435	597							
CLEARO	0456	405	19									
COMPUT	05F0	631	614									
COUNT	002A	61	129	728	729							
COUNTT	002D	64	73	74								
C1	000E	32	290	620								
C10	0017	41	317	641								
C11	0018	42	****									
C12	0019	43	323	673								
C2	000F	33	293	652	663							
C3	0010	34	296									
C4	0011	35	299									
C5	0012	36	302									
C6	0013	37	305	533	684	760						
C7	0014	38	308	538	691	764						
C8	0015	39	311	698								
C9	0016	40	****									
DATACF	001C	47	109	191	427	602						
DATACT	05B9	601	430									
DAYH	0005	22	227	229	327	558	588					
DAYL	0006	23	223	226	326	590						
DDRA	1701	6	172	411	497	711						
DDRB	1703	8	415	720								
DISOUT	03CD	338	289	292	295	298	301	304	307	310	313	316
			319	322	325	328	331	334				
DON	0288	163	149									
FEB	0310	239	247									
FETCH	0486	427	425									
FIRSTF	002C	63	408	432	434	710	724	726				
FURTH	0415	374	372									
GETKEY	049A	436	429	433								
HIGHMP	0020	51	142	160	161	655	672					
HINOWP	0029	60	258	260	352	366						
HPAGE	0027	58	356									
HRS	0007	24	217	219	222	329	586					
INCBIN	05DD	621	634	642	647	674	699					
INCPPC	0329	254	353	357	360	363						
INF	0022	53	371	499	604							

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CARD # LOC    CODE       CARD  10          20          30          40          50
       062D   69 01             ADC #1
       062F   85 1E             STA MUL1
       0631   A5 0F             LDA C2          FETCH TORQUE AND ADD 1
       0633   69 01             ADC #1
       0635   85 1F             STA MUL2        IF TORQUE = 255
       0637   B0 0F             BCS NO          DONE
       0639   20 61 02          JSR MULT        P1=(T+1)(W+1)
       063C   18                CLC
       063D   68                PLA
       063E   65 21             ADC LOWMP       P2=P1 + P
       0640   68                PLA
       0641   65 20             ADC HIGHMP
       0643   85 19             STA C12         SAVE P2 HIGH BYTE
       0645   4C DD 05          JMP INCBIN
       0648   4C C7 05   NO     JMP SCALE
       064B   C9 0D      CNNOW4 CMP #13         TIME ROUTINE
       064D   D0 03             BNE CNNOW5
       064F   4C C7 05          JMP SCALE
       0652   C9 06      ONNOW5 CMP #6          CHANNEL 6 AIR TEMP
       0654   D0 0E             BNE CNNOW6
       0656   AD 05 14          LDA $1405       START CONNVERSION
       0659   20 00 02          JSR WAIT40      WAIT
       065C   AD 05 14          LDA $1405       FETCH TEMP
       065F   85 13             STA C6
       0661   4C C7 05          JMP SCALE       GET NEW CHANNEL
       0664   C9 07      CNNOW6 CMP #7
       0666   D0 0E             BNE CNNOW7
       0668   AD 06 14          LDA $1406
       066B   20 00 02          JSR WAIT40      WAIT
       066E   AD 06 14          LDA $1406       FETCH PRESSURE
       0671   85 14             STA C7
       0673   4C C7 05          JMP SCALE       GET NEW CHANNEL
       0676   C9 08      ONNOW7 CMP #8          ANEM 2
       0678   D0 0E             BNE CNNOW8
       067A   AD 07 14          LDA $1407
       067D   20 00 02          JSR WAIT40
       0680   AD 07 14          LDA $1407       FETCH ANMEN 2
       0683   85 15             STA C8
       0685   4C DD 05          JMP INCBIN
       0688   68         ONNOW8 PLA             FINSHED
       0689   68                PLA             RESTORE STACK
       068A   60                RTS             RETURN
       068B              ;
       068B                    * = *+5
       0690              ;
       0690              ; THIS ROUTINE SAMPLES SEQUENTIALLY EVERY 1/10 OF A SEC
       0690   A2 00      SEQUAL LDX #00         CLEAR
       0692   8A                TXA
       0693   48                PHA             CLEAR PROCESSOR STATUS
       0694   85 2C             STA FIRSTF      CLEAR FLAG FIRST TIME (FIRSTF)
       0696   8D 01 17          STA DDRA        SET A AS INPUT
       0699                     ARE=IRQ2/256*256
       0699   A9 4A             LDA #IRQ2-ARE   LOAD IRQ2 LOW BYTE
       069B   8D FE 17          STA $17FE       STORE INTERRUPT VECTOR
       069E   A9 02             LDA #IRQ2/256   LOAD IRQ2 HIGH BYTE
```

SYMBOL	VALUE	LINE DEFINED	CROSS-REFERENCES									
IRQ1	0227	98	418	419	421							
IRQ2	024A	122	712	713	715							
ISOUTF	047D	423	341	439	598							
ITISO	026E	148	154	162								
KEY	04A4	440	438									
LDAYH	00C9	26	589									
LDAYL	00CA	27	591									
LESS	06C9	643	640									
LHRS	00CB	28	587									
LMIN	00CC	29	585									
LONOWP	0028	59	254	257	350	355	358	361	364	368		
LOP3	06F2	749	745	751								
LOP4	06E9	746	753									
LOWMP	0021	52	143	157	158	657	670					
LPAGE	0026	57	359	390	622	625						
ME	06BE	729	730									
MIN	0008	25	212	213	216	332	584					
MOS	02C0	418	419									
MULT	0261	141	654	667								
MUL1	001E	49	151	155	651	662						
MUL1H	001D	48	144	152	159							
MUL2	001F	50	146	153	653	665						
NEXT1	04AB	443	441									
NEXT10	04EA	470	468									
NEXT11	04F1	473	471									
NEXT12	04F8	476	474									
NEXT13	04FF	479	477									
NEXT14	0506	482	480									
NEXT15	050D	485	483									
NEXT16	0514	488	486									
NEXT2	04B2	446	444									
NEXT3	04B9	449	447									
NEXT4	04C0	452	450									
NEXT5	04C7	455	453									
NEXT6	04CE	458	456									
NEXT7	04D5	461	459									
NEXT8	04DC	464	462									
NEXT9	04E3	467	465									
NO	0648	675	666									
NOCOL	02C2	192	189									
NULLNX	0212	85	88									
NULL20	02CE	82	377	592								
ONMOR	05C0	615	613									
ONNOW1	05F9	635	632									
ONNOW2	060C	644	636									
ONNOW3	0615	648	645									
ONNOW4	0643	676	649									
ONNOW5	0652	679	677									
ONNOW6	0664	686	680									
ONNOW7	0676	693	687									
ONNOW8	0688	700	694									
ONWAR	0597	584	376									
OUT	0534	510	605	607	608							
OUTF	001A	45	107	424	596	629	766					
OUTPCK	033C	270	86	90	379	386	388	394	398	400		
OUTPUT	051C	496	426									
OUTSUB	030C	346	512	517	522	527	532	537	542	547	552	557

```
SYMBOL   VALUE  LINE DEFINED        CROSS-REFERENCES

                           563   569   574   579
POINTH   00FB        14   ****
POINTL   00FA        13   ****
PON      023F       111    108
PRA      1700         5    175   179   270   733   737
PRB      1702         7    174   178   182   184   272   274   275   413   500   594
                           718   732   736   740   742
READ     0291       169    110
RPM      0023        54    176   186   320   646   650   660
RUN      027B       155    147
SCALE    05C7       610    627   630   643   675   678   685   692
SC0      0358       287    442
SC1      035F       290    445
SC10     039E       317    472
SC11     03A5       320    475
SC12     03AC       323    478
SC13     03B3       326    481
SC14     03BA       329    484
SC15     03C1       332    487
SC2      0366       293    448
SC3      036D       296    451
SC4      0374       299    454
SC5      037B       302    457
SC6      0382       305    460
SC7      0389       308    463
SC8      0390       311    466
SC9      0397       314    469
SECN     0004        21    205   208   211
SECND    001B        46    207   502   503   505   506
SEC6     0003        20    200   201   204
SEQUAL   0690       707   ****
START    0682       723    756
STATE    0434       390    396
THERE    0313       241    237   244   245   246
THIRD    06BC       728    725
TIME     170F         9    104   128   417   722
VOL      0204        74     75
WAIMR    052A       503    504
WAISMR   0530       506    507
WAIT40   0200        72    618   682   689   696   747   753   762
WITH     041C       377    375
YEAR     000D        30   ****
```

APPENDIX G

System Operation

The KSU Wind Laboratory system operation is both straightforward and simple. Details given in this appendix include program loading procedures and actual data collection procedures.

To load the program from audio cassette:

1. Set the single step-IRQ switch to IRQ.
2. Set the TTY-DISPLAY switch to DISPLAY.
3. Set the tone on the tape player to high.
4. Set tape player volume to 1/2 plus.
5. Connect a patch cord between the output of tape player to input (IN) on the system.
6. Turn on the ± 15.7 V, + 12 V and + 5 V power supplies.
7. Follow the procedure given below by keying in the proper values:

Key	Display	Comments
RS	XXXX XX	Reset.
AD	XXXX XX	Address mode.
Ø Ø F 1	ØØF1 XX	
DA	ØØF1 ØØ	Data mode.
Ø Ø	ØØF1 ØØ	Set processor
AD	ØØF1 XX	status to zero.
1 7 F 9	17F9 XX	Tape number.
DA	17F9 XX	Address.
Ø 1	17F9 Ø1	Tape number = 1.
AD	17F9 Ø1	Address mode.
1 8 7 3	1873 XX	Tape input.
GO	Blank	Start program.

8. Start the audio cassette before the first of the program. (Rewind cassette.)

9. Finish when display shows ØØØØ 4C. If the display shows FFFF XX, there is an error in the tape read. Restart at step 1.

10. Stop the cassette player.

11. The program is ready to run in the binned data angular velocity threshold mode, after initialization of angular velocity threshold and calendar.

Calendar Time and Data

To enter the time and date, do the following:

Key	Display	Comments
RS	XXXX XX	Reset.
AD	XXXX XX	Address mode.
Ø Ø Ø 5	ØØØ5 XX	
DA	ØØØ5 XX	Data mode.
**	ØØØ5 **	Day of the year
+	ØØØ6 XX	high byte (Hex)
**	ØØØ6 **	Day low byte
+	ØØØ7 XX	
**	ØØØ7 **	Hour (24 hour
+	ØØØ8 XX	day)
**	ØØØ8 **	Minute
+	ØØØ9 XX	
**	ØØØ9 **	Last day high
+	ØØØA XX	byte.
**	ØØØA **	Last day low
+	ØØØB XX	byte.
**	000B **	Last hour
+	ØØØC XX	(24 hour day)
**	ØØØC **	Last minute
+	000D XX	
**	ØØØD **	Year (Hex)
		last two digits
AD		Address mode.

Selection of Angular Velocity Threshold

Determine the minimum value of angular velocity that data is to be recorded above and store the value at location 02BBH by keying in the following commands:

Key	Display	Comments
AD	XXXX XX	Addres mode
Ø 2 B B	Ø2BB XX	Select address
DA	Ø2BB XX	Data mode
**	Ø2BB **	

** Hexadecimal value of angular velocity threshold. Desired minimum RPM of the turbine multipled by 1.176 equals angular velocity threshold in decimal. Convert to hexadecimal before entering.

Input/Output to the Paper Tape Punch

The KIM-1 will output data to the punch when any bin is full. If the punch is punching and the data is not wanted, press the following keys:

Key	Display	Comments
RS	XXXX XX	Reset
AD	XXXX XX	Address mode
Ø Ø 1 A	ØØ1A Ø1	
DA	ØØ1A Ø1	Data mode
Ø Ø	ØØ1A ØØ	Reset output flag
AD		Address mode
Ø Ø Ø Ø	ØØØØ XX	Beginning of program
GO	Blank	Start data collection

Selection of Channels to be Recorded

Decide which channels are to be recorded and follow the format given in the listing of the output section of Appendix F. The table given in the output section dictates both data collection and output.

Data Collection by Method of Bins

After all initial inputs are made (date, time, etc.), do the following:

Key	Display	Comments
AD	XXXX XX	Address mode
Ø Ø Ø Ø	ØØØØ 4C	Beginning of program
GO	Blank	Start

Values of the current samples can be displayed by the following method:

Key and Channel Number	Displayed
1	Analog anemometer #1
2	Torque Meter
3	Electrical power
4	Alternator voltage
5	Wind direction
6	Air temperature
7	Air pressure
8	Analog anemometer #2
9	Digital anemometer
A	Delta wind speed (only positive values)
B	Angular velocity
C	Shaft power
D	Day high and low
E	Hour
F	Minute

Values are displayed in a ØØ** XX mode, where ** is the value of the channel.

Sequential Data Collection

For sequential data collection, key in the following:

Key	Display	Comments
RS	XXXX XX	Reset
AD	XXXX XX	Address mode
Ø 6 9 Ø	Ø69Ø A2	Beginning program
GO	Blank	Start

The system will return to the bin data collection mode after sequential data collection and output only the channels requested in that mode.

INSTRUMENTATION OF A SAVONIUS WIND
TURBINE

by

SAMUEL MARTIN BABB

B. S., Kansas State University, 1976

AN ABSTRACT OF A MASTER'S THESIS

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MASTER OF SCIENCE

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1979

ABSTRACT

This thesis describes instrumentation to measure performance of a Savonius wind turbine. Performance analysis requires data histograms of wind speed, turbine torque, and turbine power. These histograms are produced by a KIM-1 microcomputer and A/D system. Sensors--both analog and digital--for wind speed, wind direction, turbine velocity, turbine torque, air temperature, atmospheric pressure, and electrical power are described. Also included are the complete system software and operating procedures.